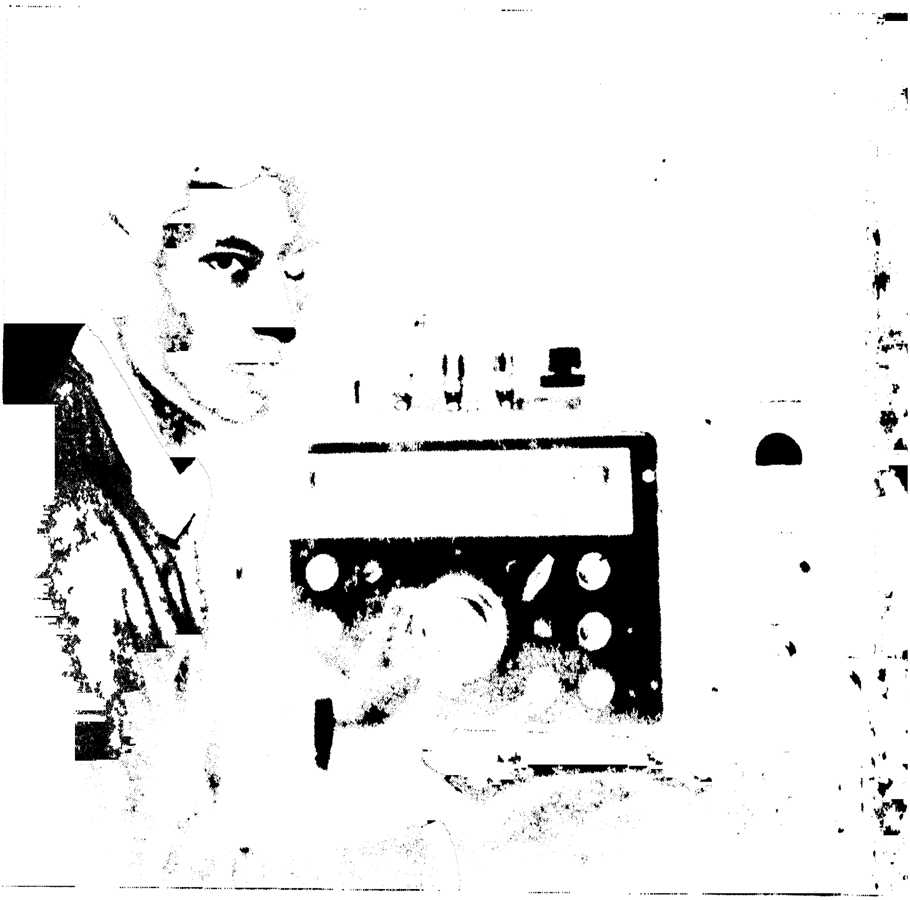
UNDERSTANDING RADIO

HERBERT M. WATSON still holds his first amateur radio license, W6EW, which he received thirty-five years ago. He is an authority on microwave radio systems and has designed many of the police, fire, and industrial radio systems in the western United States and foreign countries. As president of his own radio engineering firm near San Francisco, he pioneered the use of two-way radio systems in the West. He also owns the Watson Dispatch Radio Service, KMA617.

HERBERT E. WELCH built his first crystal set as a high school freshman in Salem, Oregon, an experience which started him off as an enthusiastic ham operator (W6PRD). After obtaining his commercial wireless license in 1920, he tested radio equipment for the Oregon Forestry Service, then spent some time at sea as a radio operator on the Alaska steamship run. Following graduation from Oregon State College, he taught radio at Lincoln Union High School and Richmond Union High School in Richmond, California. Since 1937 he has taught at Stockton College in the Radio and Engineering Drawing Departments. Mr. Welch, who is also the author of *Basic Mechanical Drawing*, made all of the drawings for *Understanding Radio*. For many summers he has been a guest professor in Industrial Arts at Oregon State College. His greatest pleasure comes, he says, from explaining difficult technical subjects in terms that beginners can understand.

GEORGE S. EBY has been an outstanding high school and college science teacher for the past four decades. He is the author of numerous articles on physical science and has produced more than seventy educational and documentary motion pictures. He has been a guest professor at Oregon State College, Florida State University, and Redlands University, and has served as a consultant on instructional materials with the Armed Forces.

THIRD EDITION



McGRAW-HILL BOOK COMPANY, INC.

Understanding RADIO

A GUIDE TO PRACTICAL OPERATION AND THEORY

HERBERT M. WATSON

HERBERT E. WELCH

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Illustrated by Herbert E. Welch

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UNDERSTANDING RADIO

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The photograph on the title page shows Perry Klein with his amateur radio equipment at his home in Bethesda, Maryland. As a high school senior, Perry and his friend Rafael Soifer of New York City were credited by the Massachusetts Institute of Technology as having conducted probably the first successful two-way radio communication with the aid of artificial satellites. On February 6, 1960, Perry and Rafael, both amateur radio operators, sent and received coded signals between their two homes by bouncing signals off the ionized trails left by satellites.

CONTENTS

TO THE TEACHER

Understanding Radio is intended especially for students with little or no background in electricity or science. The authors have written a text that these students can read and understand.

Background experiments in electronics and explanation of the fundamentals of electronics are related closely to radio equipment and usage. Radio-physics experiments allow easy self-demonstration of the principles involved.

Mathematics is kept to a minimum. The mathematics required is explained in the simplest terms. It is kept practical.

Nontechnical language and full explanations are used in the introductory chapters of this book because radio language is a hopeless jargon to the uninitiated. New technical terms are introduced gradually. New terms with definitions are collected at the end of the chapters where they first appear. Learning-by-doing makes this book valuable as a laboratory textbook. This book has been successfully used in teaching by lecture and lecture demonstration and for individual and self-instructon.

Many breadboard sets and unit circuits are presented in detail for construction by the student. Standard chassis construction is also included.

In the new edition, emphasis has been placed on visual teaching. Most of the 500 drawings have been redone in a new pictorial style. Little stick "electron men" help the student visualize circuit action. An understanding of introductory radio theory has been heavily stressed. To explain circuit action better, many why-it-works explanations have been rewritten as illustrated steps. The Hartley-oscillator discussion is an example of this treatment.

Several new circuits, tubes, applications, and principles have been introduced. Among these are public-address units, intercommunication units, the phase-inverter circuit, many new tubes, new power supply circuits, frequency modulation, and a new chapter on transistors.

You will find this new edition a better book easier for you to teach from and easier for your students to use and understand.

WHAT DOES THIS BOOK OFFER?

Who may study radio? Radio sets have for years been constructed of a simple assortment of parts by persons handy with screwdriver, soldering iron, and drill. These experimenters have proved that the field of radio is not limited to mechanics or to persons who are already familiar with electrical and radio principles. This means that you, too, can have the fun of hearing distant stations on a set that you have built or that you can have the satisfaction of being able to operate intelligently equipment you have purchased.

Whether you are a beginner in radio or an experimenter who wishes to round out his radio background and gain experience in the handling of radio apparatus, you will find in this book necessary and valuable radio information. The fundamental radio and electrical facts are explained simply and clearly. In addition to explanations, each chapter suggests and outlines practical experiences in building, operating, and studying simple and practical equipment.

The fundamentals are important. Radio is essentially simple if its fundamental principles are learned in a logical order. Such a learning order is followed in this book by combining set construction, practice in operating basic radio circuits, and a thorough study of radio principles.

Many persons have enjoyed building and operating radio sets without knowing the principles on which the operation of the set depends. You can, of course, build and operate sets by following instructions in radio magazines or other radio publications. But while you can do much experimenting without knowing the "whys" of a circuit, a knowledge of the principles of radio and their underlying electrical theory and practice is usually desirable for the person who has a permanent interest in radio either as a vocation or as a hobby.

How is the material selected and arranged? The subject matter of the book is arranged in the order in which you will need it

as you work with each set. As far as possible, each circuit is studied as a single lesson, which is divided into the following parts:

1. The Purpose of the Lesson
2. How to Build and Wire Any Needed Apparatus
3. How to Operate the Set or Apparatus
4. Why the Set Works as It Does

The explanation in "Why the Set Works as It Does" assumes that you have some understanding of common electrical principles. But if you do not know or have forgotten these principles, you will find included in the chapter experiments that demonstrate and help to explain them to you.

The "how" of set operation is given in the operating instructions. The description of each set is followed by an explanation of the theory involved. Every principle is proved by experiments which use parts found in the average laboratory or shop.

Inexpensive and easily secured parts are suggested for all the sets described in the book. The authors, as teachers, are more interested in circuits that are suited to the demonstration of certain basic radio or electrical principles than in using the most modern equipment. For example, this is the reason for using the 1LE3 tube to present the principles of the electron tube and to explain its operation. Tubes of later design, which are more efficient, may be used in place of the 1LE3 tube.

Questions which serve as a checkup on your understanding are included in each lesson.

In the list of "Technical Terms" at the end of each chapter, you will find explained the new words that are used in that chapter.

How should each chapter be studied? Follow a definite procedure as you work through each chapter to produce the best results. The following plan is suggested. You may want to omit some steps, depending upon your previous knowledge and work.

Step 1. Read the purpose of the lesson carefully.

Step 2. Then make a copy of each circuit diagram. (This is an excellent way to learn the connections for each circuit.)

Step 3. Build and wire any needed equipment. If you are using completed equipment, follow carefully the instructions for attaching the batteries or the power pack and the antenna and ground. You will find there is a right and a wrong way. (Do

not omit any experiment or hookup, because each is designed to teach you an important principle in electricity or radio.)

Step 4. Test yourself on the checkup questions. They are a good test of your understanding of the information in the lesson. Write out the answers.

Step 5. Work the experiments on electrical and radio principles. (Your understanding of radio is based on your grasp of these principles.)

Step 6. Turn to the list of "Technical Terms" at the end of the chapter to find the meaning of any technical words that are new to you.

What should be expected from this book? When you have completed the experiments outlined in this book, you will have a working knowledge of the principles that underlie radio. These principles do not change. They are the basis on which all radio sets are built, from the lowliest crystal set to the finest de luxe model. If you wish to keep up with the latest developments in radio, the current radio magazines are your best source of information. There are many of them on the newsstands.

If you are not familiar with some of the terms and abbreviations that you find in current radio magazines, look them up in the *Electronics Dictionary*, by Cooke and Markus, which is an excellent reference book.

CHAPTER 1

RADIO—SOUND'S SEVEN-LEAGUE BOOTS

Why use radio—Why not shout? Just as the seven-league boots helped the hero of fabled story to leap across impossible distances, so has the modern magic of radio given to voice the ability to leap not seven leagues but thousands of miles across mountain and valley, sweeping with the speed of light from town to town and state to state, and even to span the vast, lonely wastes of ocean between continents.

Even you, like the fabled hero, can slip on the magic "boots" we call radio and flash your voice across our country, talking to others like yourself, radio amateurs. You, too, can talk across the oceans with your homemade equipment. But there is no simple way to make your voice leap these distances without the aid of the magic seven-league boots of radio. Sound, unaided, will carry only short distances.

Shout as loudly as you can, and your voice will carry only a block or so. Build up your voice with the aid of a loudspeaker, as was done in wartime to communicate between vessels, and your voice will carry only for a few hundred yards.

Sound waves travel short distances. Terrific dynamite blasts that have occurred at powder-manufacturing plants have been heard for only a few miles. The enormous concussion produced when the volcano, Krakatao, blew up in 1883 was heard for a distance of only a few hundred miles. Such tremendous sound power is seldom available and is uncontrollable. But if we could control such power, its use would be impractical because the sound travels such short distances.

Radio waves travel great distances. Some system is needed to transmit sound or to communicate over any considerable distance. Hertz, and later Marconi, discovered such a system. They found that when electric currents were forced to surge rapidly back and

forth in the wires of an antenna, an effect, set up in space around these wires, traveled rapidly away from them. We now call this effect *radio waves.* These radio waves, we know, travel at the speed of light, or approximately 186,000 miles a second, which for all practical purposes means that a sufficiently strong radio wave will leave the antenna wires of a transmitting station and arrive at any receiving station in the world *almost* instantly. A person in Honolulu listening to a radio program from San Francisco will hear a word spoken by the performer a fraction of a second sooner than will a spectator in the studio audience in San Francisco. The radio wave reaches Honolulu and is converted into sound by the receiver before the sound reaches the person in the first row of the auditorium at San Francisco. The radio wave, which travels great distances, has been made to carry the sound or speech which we know as the radio program. Suppose you examine this process as it occurs at a broadcasting station.

Visit a radio broadcasting station to study this radio process. What would be more interesting than to start your study by going directly to a radio broadcasting studio and to a broadcasting station, where you can actually watch a radio program being broadcast? There you can begin to learn about the technical details of radio broadcasting.

A radio broadcasting station actually is made up of two separate units, the broadcasting studio, where the programs originate, and the broadcast transmitter and antenna where the programs are put on the air.

Your study of radio will be one of the most fascinating and satisfying in the applied sciences.

Visit first a radio broadcasting studio. The broadcasting station you visit has a studio located in the city, where it is convenient to musicians, singers, speakers, or others who perform before the microphone.

Here, the station manager explains, there are several studios where recordings are made, where rehearsals are held, and finally, the large studio where the main programs originate. He points out the red signal light that shows when a studio is on the air. He shows you the clock by which the staff times each program to the second, and the glassed-in operating booth for the technician.

He then takes you into the main studio. As you enter, you

note an odd feeling. This room sounds and feels different. It seems oddly quiet, with its deep soft rug and its strange atmosphere. The station manager tells you that studios must be specifically built for radio work. He shows you the hard and soft wall surfaces carefully engineered to make the voices and the music of the programs originating in this studio sound natural in your radio receiver.

He explains that each studio must be carefully built to eliminate echoes and to keep undesired outside noises from reaching the microphone. An engineer would say that the room had been *acoustically* treated. He would tell you that the absence of echo is what gives you the odd feeling in the studio.

Your visit to the broadcasting studio and to the broadcasting station will give you a chance to learn how programs that you have listened to in your home originate at the studio and to follow them through the technical steps as they are put on the air at the transmitter.

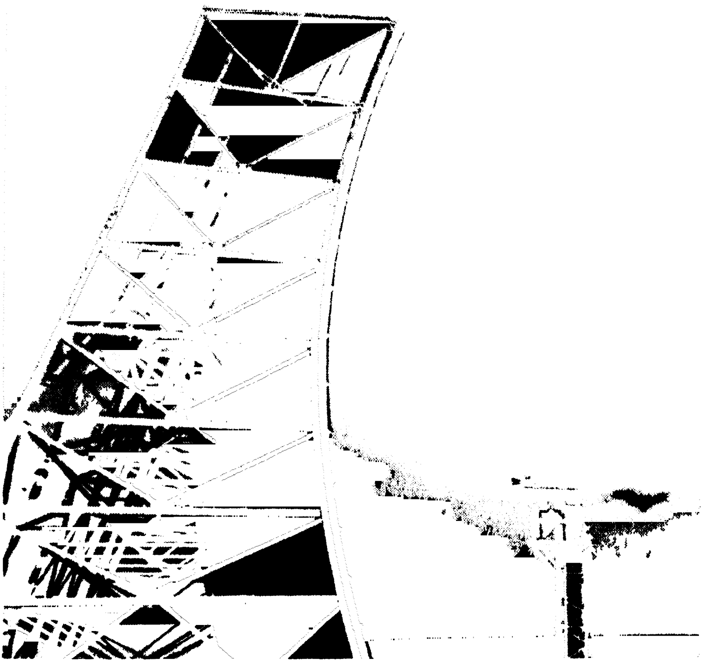
On your visit to the broadcasting station and studio, you will see highly technical and efficient equipment. You will talk with a group of men well trained in the technical phases of radio and in its practical operation. Both the equipment and the men's training represent a high degree of development, and yet you will find that you can understand in outline the principal steps in the broadcasting process, which they will show you and tell you about during your visit. You should try to understand this outline rather than becoming entangled in the technical details of the process.

Remember, as you examine this fine equipment, that the radio amateur in your neighborhood built and wired much of his apparatus and that he too sends out his voice or code messages across thousands of miles of space. He uses simpler versions of the same radio parts and circuits used by the radio broadcasting station — parts and circuits which you, too, can learn to understand and use to operate your own station.

What appears at first to be a maze of complicated apparatus becomes an orderly arrangement of working parts as you become familiar with the equipment, learn some new technical words, and do some experiments. You, too, can understand and master these technical details as you build and operate the electrical and radio

equipment and do the experiments described later in this text and as you study the principles of their operation.

When you ask the station manager why the windows in the studio are set on a slant, he tells you that this is a part of the acoustical treatment. The glass surface is slanted to prevent



Electronics

A New Type of Microwave Antenna

This 60-foot parabolic antenna near Guanabo, Cuba, concentrates signal power for its 185-mile journey to Florida City, Florida. It is part of the first commercial system to transmit over 200 telephone conversations and one television program by means of microwaves.

sound waves reflected from its surface from building up unwanted echos in the room.

But most interesting are the different microphones, or "mikes." One, the station manager explains, is used to pick up the band music or the songs of groups of singers, while others are used by the announcer and by the actors in radio dramas.

In the technician's booth, you see on a small, compact switchboard, which the manager calls a *console*, the knobs and controls that the technician uses to fade out the voice of the announcer

and to fade in the voices of the actors as changes are made to different parts of the program.

Close at hand, within reach of the technician seated at the console, you see another panel which looks like a telephone switchboard. That is exactly what this panel is. Connected to it are special telephone lines running to the broadcast transmitter, as well as lines to the radio network of which this station is a part.

Now the station manager introduces you to some of the members of his staff. You meet trained announcers and the technicians who operate the controls for the microphones at the console you have just examined and who assist or direct the actors or other performers at the studio. When you ask how the program actually gets on the air, the manager turns you over to a technician who explains the process to you.

He tells you that sound waves set up by the actor's voices, musical instruments, and so on move a thin metal diaphragm in the microphone which sets up electrical variations that follow exactly the variations of the voice or other sounds in the studio. He then shows you how these variations go from the mike to the technician's console and on into amplifiers. From the amplifiers, the strengthened voice or sound currents travel over the special telephone lines to the transmitting station.

He shows you the controls on the console which allow him properly to balance the strength of the actors' voices or the volume of the accompanying music. He tells you that he can fade in or fade out the different parts of the program by means of these controls, so that you hear a pleasant, well-balanced program.

He points out the cables which carry the program from the amplifier to the switchboard, where it starts on its way to the broadcast transmitter.

In answer to your questions about the electrical operation of the studio end of the broadcasting process, the technician explains that you must know something about sound waves and how they act on the microphones you have just seen.

How are sound waves produced? He explains how sound waves are produced when the tiny particles, or molecules, of the air are set in motion by the voice, by noises, or by musical instruments. When you speak, air molecules are alternately moved together and pulled apart by the air forced from your lungs. These molecules

bump into others, which move over and bump into still others, and so on. Each air molecule moves but a short distance and then moves back into place. This disturbance, or sound wave, travels through the air from one molecule to another at the rate of about 1180 feet per second. The power used to set these molecules in motion is rapidly dissipated as one molecule bumps into the next, and so the sound wave dies out before it gets very far. You can notice this by speaking to someone in the next room. Your hearer will find that the farther you move away from him the weaker becomes the sound of your voice, until finally he can no longer hear you.

How do the sound waves affect the microphone? The technician tells you that, while the several types of microphones in the studio operate on different principles, their purpose is the same—to transform the energy in the sound waves into electrical variations in the circuits attached to them. Furthermore, he says, the electrical variations must follow faithfully the variations in sound energy which produce them.

He shows you the cabinets which enclose the amplifiers that build up these electrical variations before they are sent on over the lines to the transmitter to be put on the air.

He suggests that you will now want to follow the program to the broadcast transmitter, where it is actually put on the air. He calls the transmitting station to arrange for your visit.

Now visit the broadcast transmitter. The transmitter is located some miles out in the open country, where conditions for a station are better than in the city. Here you see the transmitter building and the antenna towers. The operator in charge meets you and shows you through the station.

When you enter the transmitting station, the operator shows you a telephone switchboard, where connections are made to the telephone lines carrying programs from the town broadcasting studio or to lines carrying programs from other cities in the network of which this station is a member.

You go into the main transmitter room to see the amplifier and modulator tubes and panels. Here, your guide says, the wires from the switchboard bring the sound currents from the broadcasting studio or the network into the modulator of the transmitter proper. The job of the modulator tube and its circuits,

he says, is to use the sound currents to control the strength of the powerful carrier currents set up in the circuits you saw on your first visit to the station. He explains carefully how the radio waves are modulated. He tells you that when waves are modulated, they are made strong and weak in exact accord with the sound currents from the studio.

Perhaps the technical words and the names of machines or parts that he uses sound odd at first. Listen carefully and try to remember them. You will find their definitions at the end of this chapter. Your curiosity about their meaning will be better satisfied as you go on with your study of radio. You will set up and operate similar pieces of apparatus in the laboratory and set up and operate similar circuits in simplified form. You will then find them easy to understand.

The operator next shows you the big transmitter in which flow the powerful currents that start the process of sending radio waves through space. The transmitter is enclosed in a row of steel cabinets or racks about 2 feet wide and 6 feet high, all tastefully enameled and fitted with panels on which many meters and control knobs are mounted. Behind windows in the different panels, you see radio tubes glowing in the midst of a maze of wiring and strange-looking apparatus.

He shows you in the first rack the oscillator that sets up a current surging at a steady rate through circuits made up of coils of wire and the flat plates of condensers. When he tells you that the surging rate, or frequency, for this particular station is 680 kilocycles, you recognize at once that 680 is the setting of your receiver dial when you listen to the program from the station you are visiting. The engineer explains that this oscillator circuit must always be held at the same frequency. He tells you that unless this was done, you would not always find this station at 680 on the tuning dial of your receiver but would sometimes have to tune above or below 680 kilocycles to find it. He tells you about the strict rules and regulations of the Federal Communications Commission that he must know and obey so that you can hear your favorite station by turning a dial or by pushing a button on your broadcast receiver.

However, he tells you, when you tune your receiver to 680 kilocycles, you will hear nothing if no program is being broadcast,

even though the station is on the air and your receiver is picking up some of this radio power going out from the broadcast transmitter's antenna. This power, he says, is the carrier wave which flashes across space to your receiver at the speed of light. It is the power that will carry the radio programs to you, a thing that the tremendous unharnessed power of mighty Krakatao could not do. He explains that these waves will operate your loudspeaker only when they are properly controlled or modulated by sound currents which come to this transmitter from the broadcasting studio in town.

Now examine the antenna towers. Your guide then takes you out to see the antenna towers at closer range. As you walk along the path toward the towers, he tells you that the pipes paralleling the path are the coaxial (co-axial) cables which carry the power from the transmitting equipment to the antenna towers. When you arrive at the towers, he shows you the heavy concrete base which supports the tower and the large insulator between the concrete and the steel tower footing. He explains that the insulator is needed because the power from the transmitter energizes the tower itself, which acts as the antenna.

He tells you that these powerful currents surging in the tower set up the radio waves which travel through space at the speed of light.

Now, back in the station, he turns to a broadcast receiver similar to the one in your home. He points out the tubes and the circuits and the tuning knob that is used to select the station you wish to hear. He then points out a tube which modifies the carrier current that comes into the set from the receiving antenna, so that sound currents corresponding to the sound currents at the broadcasting station can be obtained from the carrier current. He finally shows you where these sound currents are amplified and sent on to the loudspeaker, where they at last emerge as sound. You will learn more about this process in later chapters.

Can you help but marvel at the wonders of electricity? You have seen it harnessed in radio circuits to change the sound waves into electrical impulses. You have learned how these impulses, flashing through space to your receiver, reach you as the jokes of a favorite comedian or the beauty of a concerto played by Kreisler.

You can study the principles of radio and learn to apply them

BROADCASTING ANTENNA *WOR-to, New York*

Towers, insulated from the earth, are now used as the actual antenna from which the radio waves spread out through space to reach your receiving set.

in circuits and in sets much simpler than the complicated equipment you saw on this trip.

You will now begin your study with simple basic circuits, so that you can follow the paths of the current surges in microphone, transmitter, antenna, and receiver and can obtain an intelligent grasp of how electricity in these circuits makes radio possible.

Questions

1. What is sound?
2. How are radio waves produced?
3. What is the speed of radio waves?
4. How long would it take a radio signal to go from your home to Calcutta, India?
5. Why use radio—why not shout when you wish to communicate over long distances?

Technical Terms

acoustics—The science of sound. It deals with the study of sound waves and how they reflect and produce echoes. A studio is treated with sound-absorbing and sound-reflecting materials so that the sound reaching the microphone produces a pleasing response in the loudspeaker of your set.

amplifier—The circuit, including one or more tubes, that strengthens or amplifies the changing currents fed into it.

announcer—The person at the radio studio who operates the microphone-circuit controls and who announces the programs. He need not be a licensed radio operator.

antenna—The overhead wire or wires into which the broadcast transmitter feeds electrical energy in the form of powerful electron surges. These surges send radio waves out through space. Many modern radio broadcasting stations use one or more towers as the antenna instead of overhead wires. The antenna is located inside the cabinet in many modern receivers.

broadcasting station—A broadcasting studio and a transmitting station. The program is presented at the studio before the microphone, from which it is carried over special telephone lines to the transmitting station. At the transmitter, transformers and motor generators change the electrical energy from the power lines into the form needed by the radio circuits in the broadcasting transmitter. The transmitter consists of a group of tubes and circuits which modify the voice currents from the microphone at the studio and deliver them to the antenna, where radio waves are sent out.

carrier wave—The radio-frequency wave sent out by the broadcasting station which travels outward through space at the speed of light. This wave, when properly modulated or controlled, carries the radio programs to your receiver.

condenser—Metal or foil plates separated by an insulator, a device for holding or storing electrical energy. You will study and learn to use condensers in a later chapter.

control panel—A desklike panel on which are mounted the many meters that tell the station operator the operating conditions of the transmitter and the power-supplying machines. Here also are the switches, knobs, and dials that the studio operator uses to keep the audio circuits in proper adjustment.

kilocycle—One thousand cycles. (*Kilo* means one thousand.) A cycle is one surge of electrons through a circuit and back—a round-trip electron surge. In radio, a kilocycle means 1000 cycles per second.

modulate—The process by which sound currents are made to modify the strength of the radio wave generated by the transmitter, so that the radio waves will carry the sound currents.

modulation—The process by which the voice currents of varying strength, set up by sound striking the diaphragm of the microphone, control or modulate the strength or amplitude of the radio-frequency carrier wave.

molecules, air—The smallest particles of air in our atmosphere.

motor generators—Machines that generate or produce electrical energy. Alternating electrical current operates the motor, which in turn drives a generator to produce direct-current electricity or alternating-current electricity depending on the internal connections of the generator.

oscillator—A circuit that sets up a steady oscillating current which surges back and forth in the coil and condenser.

radio operator—The person who maintains and adjusts the broadcast-transmitting equipment. He must pass stiff Federal technical examinations to obtain his operator's license. He is also called *radio technician* or *radio engineer*. A true radio engineer has had four years of college training or its equivalent.

radio wave—An effect set up in space by the currents surging, or oscillating, in the antenna. The radio wave travels through space at the speed of light.

sound currents—Currents set up in the circuits connected to the microphone which are caused by sound waves striking the microphone diaphragm.

studio—The special acoustically treated rooms where singers, speakers, and musicians perform before microphones.

transmitter—The part of the broadcasting station in which the sound currents modulate the oscillating currents started by the oscillator and strengthened by the amplifiers. The strengthened modulated currents are then fed to the antenna, where the radio waves are started on their way through space to your receiving set.

CHAPTER 2

RADIO WAVES AND WAVE TRAVEL

In this chapter you will study the way radio waves travel through space after they leave the broadcasting-transmitter antenna. Many people think that the radio music and programs sent out from a broadcasting station travel as air waves which the receiving set picks up and in some mysterious way changes into music. You will soon learn how they do travel.

We shall discuss the facts that are known about these waves and their action in as simple and nontechnical a way as possible. We shall use the latest generally accepted explanations for these facts and shall avoid the explanations that are in dispute.

Much research is being done to develop the uses of radio waves for industry, for pure science, and especially for the electrical and chemical field. Military devices are also important, and many of them, like radar, are finding peacetime uses.

There are many types of waves in space. Radio waves are used in many fields other than radio. They and their effects are found in places unsuspected by those who have done little reading on scientific topics. The concentrated research on these waves is bringing out new uses for them and is revealing their existence in startling fashion. Few would suspect that light, heat, the X ray, and many other common effects are due to the same type of wave. Later in this chapter you will read more about them.

There are many wave bands. Most of you are familiar with the several wave bands used by the broadcast, police, and aircraft radio services. But you may not be so well acquainted with the amateur bands of frequencies or with the *high-frequency* or *ultrashort* (*ultra-short*) *radio waves*. Nor may you be familiar with the low frequencies used by the commercial radio-telegraph companies.

It is a highly fascinating chapter of science that deals with frequencies far higher than the highest radio frequency. You will

delve somewhat into these things in your study of waves and wave travel.

In this chapter you will learn the following things:

PART 1: WHAT RADIO WAVES ARE

Radio waves cannot be pictured accurately. If you do not know much about radio waves just now or do not understand how they act, you need not feel badly about it. You will learn more about them in later studies of radio. Also, do not think that all you have to do is to read an article on radio waves to have a definite mental picture of them.

Most of the ways used to describe and to picture radio waves are inadequate and incomplete. Do not let that discourage you. Try to form a picture even if you find it difficult to do so. Scientists and engineers use mental pictures. They change them or make up new ones when they find that the old ones are inadequate or incomplete. The important thing is to know that your picture is incomplete and to be ready to change it when you find out more about radio waves.

Electrical effects travel through space. Many theories have been advanced as a means of explaining the effects that we know occur in radio. From the mathematical studies of Maxwell and from the experiments of Hertz and Marconi in the 1800's, there was evidence that *something* traveled from the transmitter to the receiver. At first it was thought that this effect was carried by the air, but later experiments have proved that it will travel through empty space where there is no air, just as light waves from a distant star travel to us through empty space.

Only mathematical formulas describe radio waves. So-called *radio waves* are peculiar. Scientists have found that mathemati-

cal formulas are the most satisfactory way to describe and to work with them. These waves behave like trained seals when they are caged in mathematical formulas, but when they are removed from the mathematical cage, they are so complex that we are unable to form a satisfactory and accurate picture of them.

It is fortunate that you can use and enjoy radio waves before you gain an exact knowledge of them. However, there are general points which you should know.

Questions

1. Is it possible to understand the action of radio waves without first having a mental picture of them?

2. What is the one sure means that scientists have for explaining the action of the radio waves?

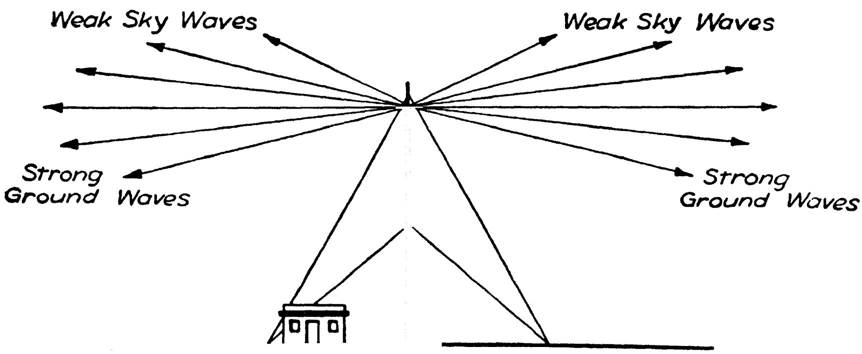


FIG. 1. Radio waves, traveling away from a broadcasting antenna, are strongest in a direction parallel to the earth. Here the ground wave is stronger than the sky wave.

Antennas send out ground waves and sky waves. When you visited the radio broadcasting station, you saw nothing unusual about the vertical steel antenna tower, but you knew that radio waves were flashing away from it at the speed of light. The engineer at the transmitter told you that the waves from this antenna traveled away from it most strongly in a direction parallel to the earth (see Fig. 1). He called them *ground waves*. The designers of the station wanted as little as possible of the energy from this antenna to be directed upward to form what are called *sky waves*, because they wanted to produce a strong, usable program at all receivers for a distance of 50 to 100 miles. If there were too little energy in the ground waves, they would be too

weak to operate an ordinary receiver well at that distance, because some of the energy in the ground waves is absorbed by the earth and some by buildings, power lines, other metal structures, trees, and so on.

The sky waves, which are directed upward, often travel surprising distances. It is the sky wave which brings you a distant station on cold, clear nights.

The engineer explained that this tall tower was designed to send out powerful ground waves. He also told you that there are other types of antenna that send out strong sky waves and

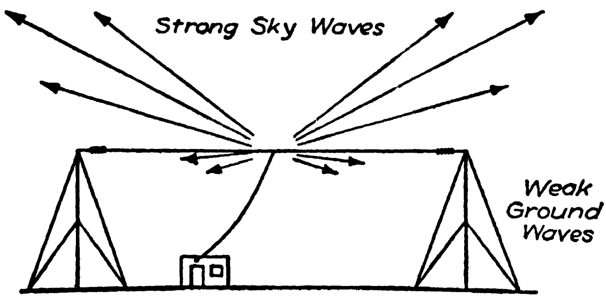


FIG. 2. Radio waves, traveling away from the antenna of a high-frequency station, are strongest in the direction shown. Here the sky waves are strong and the signals carry over longer distances.

weak ground waves (see Fig. 2). These later types of antenna, to cover greater distances, take advantage of the skipping effects described later in this chapter. Amateur stations usually depend on this sky-wave transmission. You will study more about antennas in a later chapter.

Now you will see how the radio waves travel through space from the antenna of the broadcasting transmitter to the receiver in your home.

PART 2: HOW THE HEAVISIDE LAYER, OR IONOSPHERE, REFLECTS RADIO WAVES

How do waves travel? Radio waves move, are carried, or pass through space in some way. No matter what the length or frequency of the radio wave, it moves through free space at the speed of light—186,000 miles per second (or 300,000,000 meters per second.) The speed of wave travel is so great that a wave could flash seven times around the earth at the equator in 1 second.

Radio waves generally travel in a straight line, but they may be bent, or reflected, like light. Metal interferes with these waves. The exact form or manner in which this wave motion travels is a matter of much discussion among advanced scientists, and we shall not go into it in this book.

The Heaviside layer, or ionosphere, reflects radio waves. An effect called *fading* has always interfered with reception of programs. This effect is noticed at broadcast frequencies, although it is pronounced in amateur sets on higher frequencies. Amateurs have also known the effect of the waves' "skipping" over their stations. The explanation of fading and skipping is based on the Heaviside-layer theory. This theory was developed by an Englishman named Heaviside and by an American named Kennelly. These men reasoned that there was a layer made up of electrified, or ionized, particles of air enveloping the earth at a considerable height. It is now called the *ionosphere*, or the Heaviside layer. They also reasoned that this layer of ionized particles must have a reflecting effect similar to that of a mirror.

A beam of light that strikes a mirror at an angle is reflected at the same angle. Since radio waves act like light waves, it is possible to explain fading and skipping by saying that in the sky a layer of some sort reflects the waves. It is generally accepted at the present time that there are several such layers. They have been studied enough so that we think that we understand their characteristics with reasonable accuracy.

Questions

1. What effect does the ionosphere, or Heaviside layer, have upon radio waves?
2. Does a radio wave reflect at the same angle at which it strikes the ionosphere layer?

PART 3: HOW THE IONOSPHERE-LAYER HEIGHTS VARY

How are the ionosphere layers formed? The ionosphere layers are formed as the ultraviolet rays from the sun reach the upper layers of air and use their energy in electrifying, or ionizing, the air particles they meet. When the sun is overhead, the ultraviolet rays penetrate farther through the air layers surrounding the earth. As a result, the ionization, or charging, of the air is heaviest at noon.

The constant change in the strength of the flow of ultraviolet

rays from the sun causes the ionosphere layers to billow and flow much as a cloud does. Their volumes and heights change from hour to hour as the strength of the ultraviolet rays changes.

At what heights are the ionosphere layers? Over the day side of the earth, at a height of about 70 miles, there is an ionized layer

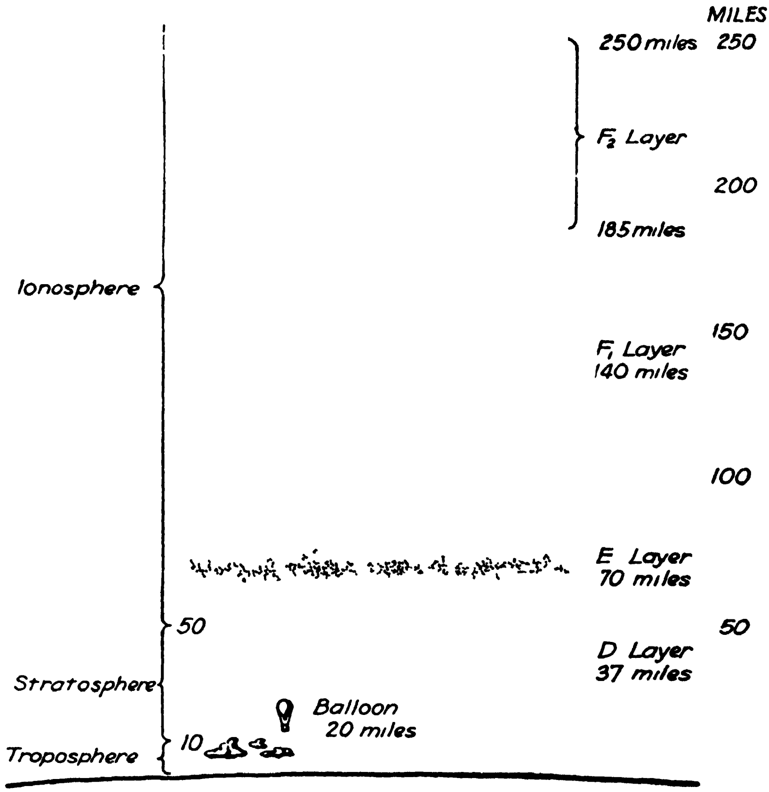


FIG. 3 Day heights of the ionosphere layers Careful scientific tests seem to show that there are several layers or concentrations of ionized air at various heights above the earth as shown in this diagram They are called *ionosphere* or *Heaviside* layers

that reflects sky waves from broadcasting stations (see Fig. 3). This is known as the *E layer*. Far above are the F_1 layer, at a height of about 140 miles, and the F_2 layer, at a height of about 185 to 250 miles. Sky waves from short-wave, or high-frequency, stations reflect from the F_1 layer during the daytime.

Below the *E* layer in the daytime there is a *D* layer at a height of about 37 miles. It has some effect on long-distance reception

of broadcasting stations. Very long wave stations (operating at frequencies below about 500 kilocycles) make some use of this layer for their transmissions.

At night the E layer remains at about the same height as during the day, but it is a much less effective reflector (see Fig. 4). At

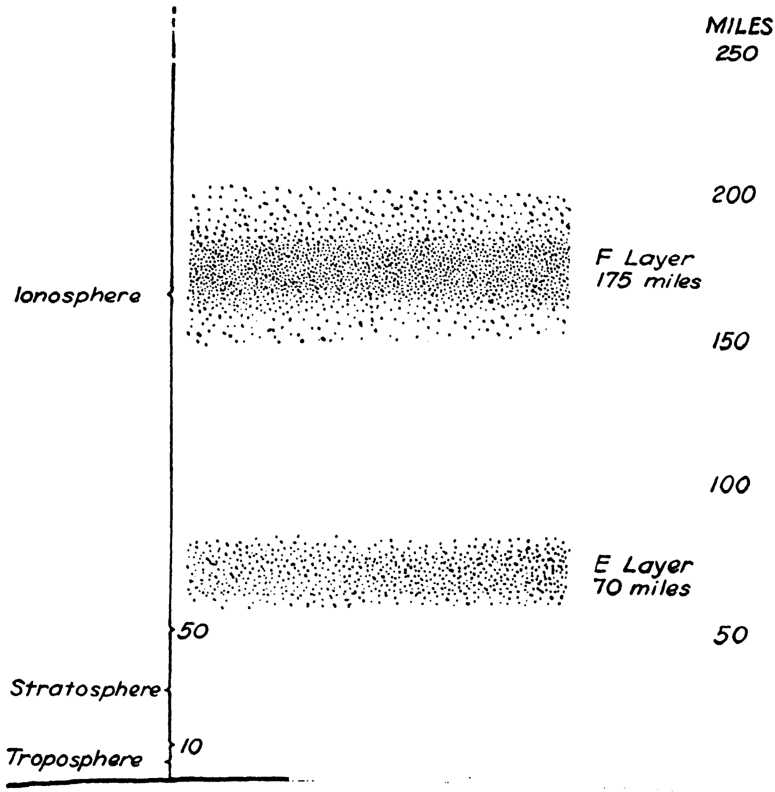


FIG. 4. Night heights of the ionosphere layers. There is no F_1 layer at night and the E layer is weak and sometimes disappears.

night there is only one upper layer, at a height of about 185 miles. It is called the *F layer*, since the F_1 layer disappears.

Questions

1. What rays from the sun cause or produce the ionosphere layers?
2. What effect does the position of the sun have on the height of the ionosphere layers?
3. Do all radio waves travel at the same speed? What is this speed?
4. What bends the radio waves around the earth?
5. Of what is the ionosphere composed?

6. The ionosphere layers are about how many miles above the surface of the earth during the day? at night?

PART 4: HOW SUNSPOTS AFFECT RADIO RECEPTION

A sunspot is a huge hole torn in the surface of the sun by an explosion of gas. An inner layer of the sun, exposed by the explosion, is at a temperature of about 30,000°F, or 20,000° hotter than the outer layer. A huge blast of ultraviolet rays rushes to the earth from the sunspot. These rays may cause the thickness and the strength of the ionosphere layers to increase as much as a third or more in an hour.

When the ionization, which is caused by the sunspots, becomes thick enough at the North Pole, it is visible as the northern lights (aurora borealis). Radio, cable, and telegraph service is often interrupted when these displays of the aurora occur. The effect of the ionization at the earth's magnetic poles, seen as the aurora, creates a tremendous field of magnetic force which causes this disturbance in radio and telegraph communication systems. Compass magnets are also badly affected by the aurora.

PART 5: WHAT SKIP DISTANCE MEANS

The ionosphere layers act like a mirror to reflect radio waves. A transmitting station sends out a wave, which strikes an ionosphere layer, reflects back to the earth, glances from the earth

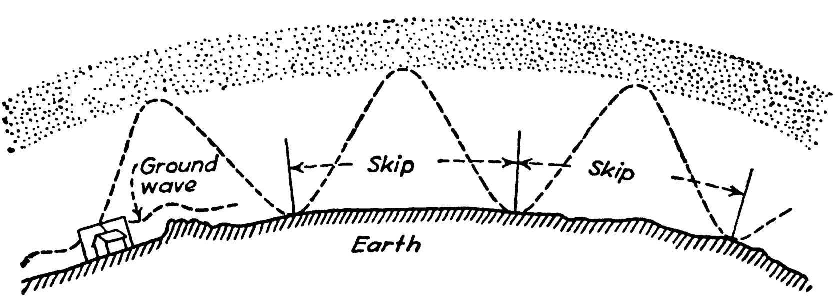


FIG. 5. Skip distance—day.

up to the ionosphere layer, then down again, and so on, until its energy dies out. This process carries waves for great distances (see Figs. 5 and 6).

Suppose your receiver is too far from the transmitting station to pick up its ground waves, which travel for short distances along

the earth (see Fig. 5). Radio sky waves which are reflecting back and forth between the earth and an ionosphere layer may strike the earth 10 miles from your set, then reflect up to the ionosphere layer, and then strike the earth again beyond your set. The set will be in a dead space between the reflected waves, but listeners beyond and behind you will receive the program. The distance between points where the reflected wave reaches the earth is called the *skip distance*. The wave that is sent from the transmitting

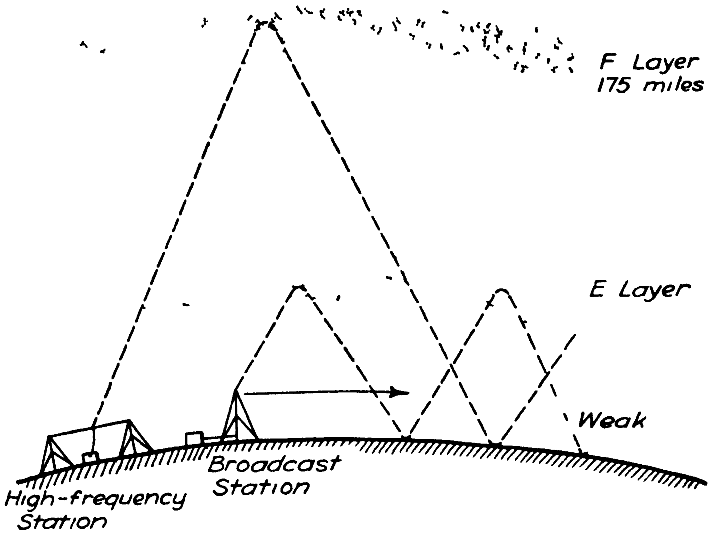


FIG. 6 Skip distance of radio signals at night

station to the ionosphere layer is called the *sky wave* to distinguish it from the ground wave.

This reflection of waves is one reason for the varying difference in volume of signals, or sounds, received from nearby stations and stations located great distances from the receiver. It is not always possible to judge the distance between the transmitting station and the receiving station by the volume of signals. In many cases, listeners have noticed that stations located thousands of miles away come in stronger than stations located only a few hundred miles distant.

Questions

1. What is skip distance?
2. What causes skipping?
3. What is likely to happen to radio waves that are sent nearly straight up?

4. What is likely to happen to waves that are sent out in nearly a horizontal direction?

PART 6: WHY NIGHT RECEPTION IS BETTER THAN DAY RECEPTION

Broadcast reception from distant stations is improved at night. Programs are heard over greater distances, and the music is stronger. At night there is less absorption of the strength of the sky waves than during the day.

Programs from the higher frequency stations also are heard over greater distances at night, because the F layers then combine into one layer at a height of about 185 miles. The F_1 layer disappears, so that the sky waves travel up to the night F layer before they are reflected. This greater height gives waves from the broadcast band to the ultrahigh- (ultra-high-) frequency waves a much longer skip distance at night.

Programs from distant broadcast stations reach you at night by way of the sky waves. You can have much pleasure searching for these distant stations. Broadcast engineers depend on the ground waves to get their programs to nearby listeners during the day. They expect these waves to furnish good programs over a distance of about 50 miles.

PART 7: WHAT CAUSES FADING

Of the many interesting explanations for fading we shall discuss but two.

Interference between ground wave and sky wave causes fading. Assume that you are close enough to a broadcasting station for the ground wave to reach your set. It could be possible for the sky wave to reflect up about 70 miles to the E layer and back down 70 miles to your set, so that you would be able to get signals from both the ground wave and the sky wave (see Fig. 7). But the sky wave has traveled a greater distance than the ground wave, and, consequently, the waves that come to you over the sky wave arrive a little later than the ground wave. A radio engineer would say the two waves are out of phase. The result is that two sets of waves interfere, and the waves are weakened or completely stopped.

The height of the ionosphere layer constantly changes. When the ionosphere layer rises, it increases the reflection distance,

and the sky wave goes beyond your set; when the ionosphere layer drops, the wave reflects on the near side of your set. Both times you hear the program over the ground wave, but when the sky wave and the ground wave reach your set together, you will hear variations in the strength of the program.

Billowing of ionosphere layers causes fading. Another cause of fading is the billowing of ionosphere layers. Suppose you are a long distance from the transmitter and in just the right position for the sky wave to reflect on an ionosphere layer and hit your receiving set. You are now too far away to receive the ground wave. As the ionosphere layer rises or billows upward, the wave

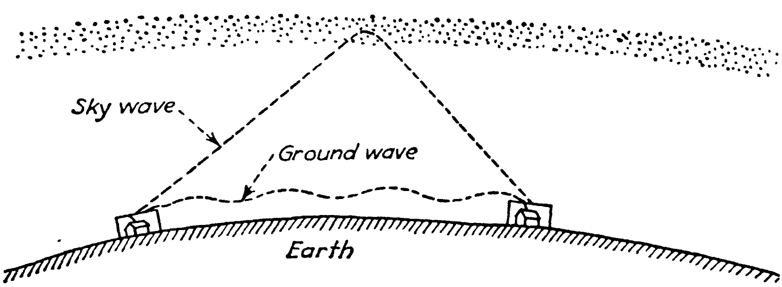


FIG. 7. Cause of fading—day.

hits the ground beyond your set and the station fades out. Then, as the ionosphere layer comes down again, the wave drops back and falls on the other side of your set.

The ionosphere layer may billow up and down so rapidly that it is possible for the wave to come in and disappear several times in a few minutes, and sometimes the fading in and out may be very slow.

Questions

1. Describe two causes of fading.
2. What causes a station to fade in and out quite rapidly?

PART 8: HOW WAVELENGTH VARIES WITH FREQUENCY

Why do some waves have high frequency and some low frequency? When listening to a conversation between radiomen you hear the words *wavelength* and *frequency* used a great deal. Probably, without realizing it, you use one of these words yourself every time you tune your radio set to hear your favorite news-

caster or evening program. You hear the announcer remark, "You are tuned to station so and so, 680 on your dial." The "680" is the frequency of the station in kilocycles. But what does that mean?

You can see the meaning of frequency clearly by doing a simple experiment with two yardsticks. Fasten the two yardsticks firmly side by side in a vise, so that one stick extends 30 inches and the other 12 inches above the vise. Then pull the end of the longer stick backward and release it. It swings back and forth rather slowly. Next, pull the end of the shorter stick in the same way and release it. The shorter stick vibrates back and forth more

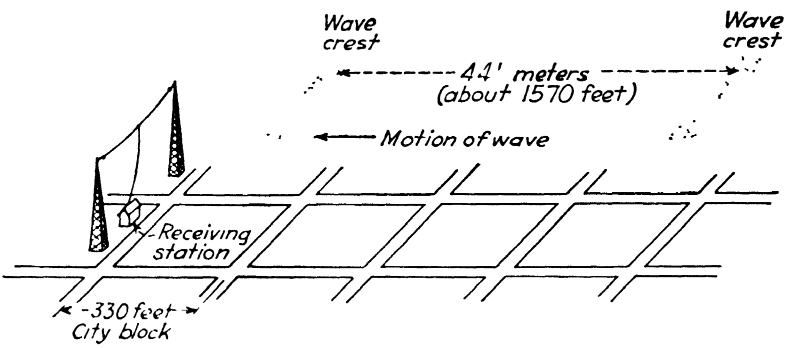


FIG. 8. One wavelength is the distance between two wave crests. For a transmitting-station frequency of 680 kilocycles one wavelength is 441 meters or about 1570 feet.

rapidly. We say that the longer stick vibrates at a lower frequency than the shorter stick. We mean that it vibrates fewer times in a second. The shorter stick vibrates at a higher frequency than the longer stick. From this you can see that *frequency* means the number of times the stick vibrates in 1 second.

In radio, the word *frequency* means the number of current surges occurring in the antenna or in the circuits of the set in one second. Each round-trip surge is called one *cycle*. Since *kilo* means one thousand, the announcer mentioned above meant that round-trip surges of current occurred in the antenna at his transmitter at the rate of 680,000 cycles per second.

It is customary to omit the words *per second* when stating the frequency of a radio wave. Thus, we say "680 kilocycles" when we mean "680 kilocycles per second." This will cause you no

confusion if you always remember that *per second* is understood when someone says that a frequency is so many kilocycles.

Wavelength is the distance a radio wave travels away from the transmitting antenna through space before another current surge starts a second wave. The wavelength of the 680-kilocycle (per second) wave we mentioned in the last paragraph is 441 meters, or about 1570 feet. A meter is a little longer than a yard.

Frequency varies with wavelength. You can always find the wavelength if you know the frequency; or you can find the frequency if you know the wavelength. All you do is divide the speed of the wave by the frequency to find the wavelength, or divide the speed by the wavelength to find the frequency. You must be careful to use the proper units. The answer will come out right if you use 300,000,000 (meters per second) for the speed. This is the rate at which the radio wave moves through space (186,000 miles per second). Then dividing by the frequency in cycles (per second) will give you the wavelength in meters, and *vice versa.*

Here is an example: The wavelength for the frequency of 680 kilocycles (680,000 cycles) mentioned earlier in this chapter equals 300,000,000 meters per second divided by the frequency. This may be written as a formula:

$$\frac{\text{Speed of wave}}{\text{Frequency}} = \text{wavelength}$$

You can write this more simply by using these symbols:

$$\frac{s}{f} = \lambda$$

where s = speed of the wave in meters per second
f = frequency in cycles per second
λ = the Greek letter lambda used for wavelength

$$\frac{300{,}000{,}000}{680{,}000} = 441.1 \text{ meters - the wavelength}$$

You can also find the frequency if you know the wavelength. A popular wavelength used by amateurs is 40 meters. What is its frequency? Substitute the known values in the formula:

$$\frac{s}{\lambda} = f$$

$$\frac{300{,}000{,}000}{40} = 7{,}500{,}000 \text{ cycles per second}$$
$$= 7500 \text{ kilocycles}$$

This amateur band actually covers the frequencies from 7000 kilocycles to 7300 kilocycles.

It is important to remember that the higher the frequency, the shorter the wavelength. Imagine that you are a timer at an auto racing track where all the cars are passing you like waves at a constant speed of a mile a minute. If the cars (waves) are all separated from each other by 1 mile, a car will roar past you once every minute. If, on the other hand, the cars (waves) are only ½ mile apart, two of them will pass you every minute. Thus, when the distance between cars (waves), or wavelength, is cut in half, the number of cars (waves) per minute, or frequency, is doubled.

Ultrashort wave bands act like light waves. The wavelengths shorter than about 10 meters act much like light waves. These waves do not seem to penetrate objects as readily as do the longer waves, but are reflected from buildings and hills as light is reflected from a mirror. Certain objects, which are large compared to a wavelength, stop the waves entirely. It is not always possible to send or receive messages with these waves, unless a system can be developed that will permit the wave to be reflected from one station to the other, because the sky wave is not reflected back by the ionosphere layers in the same manner as are ordinary radio waves.

A great deal of development has occurred in the field of the very high frequencies. These frequencies will be referred to again in later chapters.

Questions

1. What do we mean by saying a radio wave is 400 meters in length?

2. Explain the meaning of the term *frequency*.

3. What is the meaning of the word *kilo*?

4. What is the wavelength of a radio wave that has a frequency of 1500 kilocycles?

5. What is the frequency of a radio wave 500 meters in length?

6. What is the range in meters for the broadcast band?

7. What is one striking difference between a 5-meter wave and a 200-meter wave?

PART 9: HOW THE IONOSPHERE AFFECTS BROADCAST FREQUENCIES

How was the broadcasting station we mentioned built so that its ground wave would cover an area that would be within a circle of roughly 50 to 100 miles from the transmitting station while operating at a frequency of 680 kilocycles? Its antenna was built so that it would send out strong ground waves and weak sky waves. The area covered by the waves that the station sends out depends upon the amount of power the station can transmit. The station's designer controls this area by carefully planning the size and shape of the antenna.

The Federal Communication Commission has assigned to broadcasting stations frequencies between 550 kilocycles and 1500 kilocycles. At these frequencies, the transmitting antennas are not awkwardly large, and there is reasonably little loss in the ground wave. During the day, the energy in the sky waves at these frequencies is lost in the D and E layers. At night, the sky wave is reflected from the E layer and broadcasting stations are heard up to distances of 3000 miles. Fading may be noticed at night where the sky waves and ground waves oppose each other, but this effect does not occur in the 50- to 100-mile range if the station has been well planned.

The high-frequency stations, with frequencies of 1500 to 30,000 kilocycles, use the sky wave because the ground wave losses are so high. The sky waves reflect from the F_1 layer during the day and from the F layer at night. You may hear stations 10,000 miles away.

Questions

1. Explain the term *frequency.*

2. Tune your home broadcast receiver to a station of known wavelength or frequency. Then estimate how far down the street a wave crest is at the instant that a like crest strikes your set. (Assume that 1 meter equals 3 feet.)

PART 10: SOME OTHER ELECTROMAGNETIC WAVES

How do heat waves compare with radio waves? When the wavelength is shortened to about 0.0008 centimeter, it is no longer called a radio wave but is known as a *heat wave.* Heat waves are shorter, and their frequency is greater than that of radio waves.

Heat waves vary considerably in length. When you feel the heat from a stove on your hands, the stove is "broadcasting" to you on an extremely short wavelength. During the First World War, heat waves were generated, focused, and controlled so that it was possible to send messages on them. Equally amazing developments were made during the Second World War.

How do light waves or rays compare with heat and radio waves? Short waves are known as *rays.* When the heat rays get quite short, they are no longer known as heat rays but are called *infrared rays.* If the wavelength of these rays is shortened just a little more, until their length is 81 millionths of a centimeter, they produce the sensation of red to the eyes. As the rays get still shorter, they produce the effect of orange, then yellow, green, blue, indigo, and violet. The violet light is produced by the shortest ray visible to our eyes and is 41 millionths of a centimeter long. The length of light rays can be pictured easily by imagining an ordinary human hair which has been split lengthwise into 100 pieces. The thickness of one of these pieces is approximately the length of a light wave.

In other words, the waves that produce the effect of light are just the same as radio waves, but they are shorter. The radio receiver, then, is a machine for "seeing" waves that are too long for our eyes to tune in or for the nerves in the skin to feel. The receiver changes these waves into sound.

As the waves become shorter than 41 millionths of a centimeter, they again become invisible and are known as *ultraviolet light.*

X rays act much like radio waves. The next shorter wave that is interesting to us is called the *X ray.* It has a wavelength of 1 billionth of a centimeter, or it is about one $\frac{1}{1000}$ as long as visible light rays. The X ray has a property similar to that of the radio wave and different from that of the light wave in that it can pass through wood and other opaque, or nontransparent, objects. Dense objects like iron and lead, however, will stop the X rays.

How do cosmic rays compare in length with other waves? The shortest wave known is the *cosmic ray.* Its wavelength is about $\frac{1}{15}$ the length of the X ray. It can penetrate over 14 feet of lead. The cosmic ray, once the headliner among the different waves, now gives way to radar and other wartime developments using radio waves approximately an inch long.

There are many other rays which we have not mentioned because too little is known about them or they are not commonly used. There seem to be but few breaks, or gaps, in the wave bands between the shortest (cosmic) waves and the longest (radio) waves.

Questions

1. What are the wavelengths of light rays?
2. Can radio waves pass through a wooden building? Can light waves? Can X rays?
3. What is the name for waves a fraction of an inch long?
4. Can messages be sent on waves which are a fraction of an inch long?

PART 11: WHAT CAUSES STATIC

There are many causes of static. Static is a term that is usually applied to a disagreeable hissing, cracking, or popping noise in the receiver. One kind of static is caused by atmospheric electricity. Man-made static may be caused by a sparking motor or by a broken or defective insulator on a power line from which the current is leaking off to the pole. These sparks send out radio waves, most of which cover a wide band of frequencies and cannot easily be tuned out. The waves may be picked up on neighboring sets regardless of what station is tuned in. Static caused by atmospheric storms and by lightning often affects sets thousands of miles away.

Static in broadcast receivers is no longer the problem it once was, because it can be greatly reduced in a modern receiver, and because present-day broadcasting stations are more powerful. It is only strong static from the nearby arcing of current across a leaky insulator, or something of that nature, that interferes with these sets. The frequency-modulated-wave (or f-m) system is designed to eliminate static. One part of the receiver circuit is especially designed for this purpose. This system, free from static and designed for unusually good tone quality, is replacing the older amplitude-modulated-wave (or a-m) system for certain purposes, such as police radio, taxicab dispatching, etc.

How are noises minimized? Lightning and northern lights send out powerful waves which interfere with programs. Diathermy machines are considered a serious offender in sending out man-made static.

Sparking at the brushes of many kinds of motors causes static.

Static is eliminated on a noisy motor by putting condensers across the wires to the base plug or power outlet. A good illustration of static elimination is in automobile radios. Each spark plug is fitted with a suppressor resistor so that as the car runs, there will be little or no interference with the radio reception. Amateurs operating receivers on the higher frequencies can hear the static from the ignition systems on passing cars.

Questions

1. Make a list of causes of static.
2. List some ways by which static may be overcome.

Technical Terms

aurora borealis—A beautiful colored display of ascending streamers and light, caused by a thick ion cloud in the sky over the north magnetic pole.

broadcast bands—A band of frequencies from 550 to 1500 kilocycles assigned to standard broadcasting stations.

cycle—The surge of current through a circuit or an antenna in one direction and its return.

fading—The decrease in strength or the total loss of a received signal.

frequency—The number of current surges occurring in 1 second in an antenna or in a circuit of a set. See wavelength and frequency.

ground wave—A radio wave which travels along the earth for comparatively short distances.

heat Waves about 0.0008 centimeter in length. These waves cause a sensation of warmth when they fall on the skin.

Heaviside—An English scientist who developed the theory of the Heaviside layer at the same time that Kennelly in America developed a like theory.

Heaviside layer, or ionosphere—A layer of electrified particles of air that blankets the earth at a height of 40 to 250 miles. These layers are now called the *ionosphere*.

high frequency—The frequency at which short waves oscillate.

in phase Waves coming together so as to add like effects.

ionization -The partial breaking up of atoms or molecules into electrical charges. At the instant of ionization, the atoms either gain or lose electrons.

light Waves of the correct length to affect the eye. Light waves are from 81 millionths of a centimeter to 41 millionths of a centimeter long.

low frequency—Frequency at which long waves oscillate.

Marconi The Italian scientist and inventor who made the first practical application of the principles of telegraphy without wires.

out of phase—Waves coming together so as to oppose each other in effect.

radio wave An effect that travels through space at the speed of light (186,000 miles per second).

signal -The energy set up in the circuits of your receiver is often referred to as the *signal*.

skip distance—The distance between the points where the wave leaves the earth and where the reflected sky wave returns to the earth.

skipping—A billowing, or raising and lowering, of the ionosphere layers that causes reflected waves to strike the earth over certain areas and to miss, or skip, other areas.

sky wave—A radio wave which travels to the ionosphere and is reflected back to earth.

sunspots—Huge holes torn in the sun's surface by gaseous explosions.

ultraviolet rays—Waves just too short to be seen, shorter than 41 millionths of a centimeter and longer than 1 billionth of a centimeter.

wave bands—A group of frequencies or wavelengths. Light wavelengths cover a narrow band of frequencies, as do amateur-radio wavelengths, police-radio wavelengths, and broadcast wavelengths.

wavelength and frequency—As a wave gets shorter, its frequency increases, and as the length of a wave increases, its frequency decreases.

X rays—Waves about a billionth of a centimeter long. X rays penetrate wood, metal, and many other materials through which light or heat will not pass.

CHAPTER 3

SOMETHING ABOUT ELECTRICITY

When you visited the broadcasting studio and, later, the broadcasting transmitter station, where the radio waves start out through space, you saw many examples of electricity at work. You were told that the voices of the announcer and of the actors controlled the strength of the electric currents flowing through the microphones into which they spoke. You saw motor generators supplying electricity to operate the broadcasting transmitter. You saw electricity at work in rows of tubes and circuits in the transmitter racks. You were told that the radio waves leaving the transmitter antenna travel through space and set up a series of electrical happenings in your receiver set and that these electrical happenings finally cause the loudspeaker of your set to produce sound. It is easy to see why you must know a good deal about electricity if you are to understand what is going on in the studio and the transmitter circuits, as well as in your radio receiver.

Consequently, your study of radio must start with the study of electricity. You will want to know what electricity is, how it acts, what happens when it flows through the coils in your radio set, what it does in going through the maze of wires beneath the chassis, and how it acts in vacuum tubes.

In this chapter you will learn enough about electricity to be able to understand its action under these different conditions. Then, as you progress in your study of vacuum tubes and circuits, you will be able to follow intelligently the flow of electricity through them. You will learn some of the fundamental facts about the atom and electron and how the flow of electrons through wires makes an electric current. You will learn the words used to describe the flow of electricity and some of the units used to describe this flow accurately under different conditions.

You will begin to learn about electricity by studying and working with a direct current in which the electricity flows continuously

in one direction. Then later you can study alternating current, in which a special kind of generator makes the electricity flow through the wires first in one direction, then in the other. Both kinds of electricity are used in radio.

The things you will learn in this chapter are under the following headings:

Part 1: What Electricity Is
Part 2: How Voltage, Current, and Resistance Are Measured

PART 1: WHAT ELECTRICITY IS

What are atoms and molecules? It will be valuable for you to know some of the things scientists, in their study of physics, have learned about the nature of the force we call electricity. Scientists, in their age-old search to find the basic units of matter, found, as they carefully examined solids, liquids, and gases, that they could by chemical means break down each substance only so far. Materials that could not be broken down any further by chemical action were called *elements*. Examples of elements are such metals as copper, iron, and silver and such nonmetals as oxygen, nitrogen, and hydrogen. Air they found to be composed of a mixture of elements oxygen, nitrogen, small quantities of neon, argon, and a group of other rare gases.

As a result of many years of exhaustive studies made by scientists, 92 of these basic, naturally existing elements were discovered. During atomic-bomb research, a number of new elements, which are not known to exist naturally, have been identified. You can learn more about them in any recent chemistry textbook.

It was discovered during the study of matter that if elements, such as copper, iron, or aluminum, were reduced to what scientists first thought were their smallest divisions, each particle would be so tiny that several billion would be needed to reach across a pin point. This type of particle was called an *atom*. It was also discovered that the atoms of a given element are alike and that if the atoms of certain different elements are chemically held together, they form a *compound*. You are probably familiar with the combination of two atoms of hydrogen and one atom of oxygen to form a molecule of water. Science gave the name *molecule* to the smallest particle of substance that is made up of atoms of different elements chemically combined.

For years these two units, the atom and the molecule, were believed to be the smallest possible divisions of matter. But scientific evidence rapidly accumulated to prove that matter can be separated even further.

An atom consists of electrons and other particles. Since scientists are curious and skeptical, they began to question the idea that the atom was the smallest particle of matter. Evidence began to accumulate which indicated that the atom was made up of particles still smaller. A newer theory stated that all matter was made up of very tiny particles, some positively charged, some negatively charged, and some carrying no charge at all.

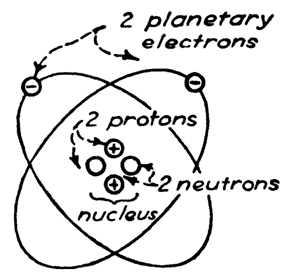


Fig. 9. This is a helium atom as Bohr would draw it.

In trying to explain the nature of the atoms, the Danish scientist Bohr (pronounced b-o-r-e) thought of a convenient way of picturing them. Figure 9 shows his picture, or diagram, of the helium atom in which he showed a heavy central core called the *nucleus*. Around it he showed two negatively charged particles called *electrons*. These two electrons move around the nucleus as the earth and the other planets move around the sun. They are called *planetary electrons*.

It is now known that the differences among atoms of different chemical elements consist basically in the differences in their nuclei. The electrons of the atom of the element are arranged in layers, and the electrons of each layer whirl around the nucleus in their own orbits.

Study the atom further. Look closely at Bohr's diagram of the atom of helium (see Fig. 9). Note that the nucleus is made up of several particles shown here as small circles. Some of these particles, called *protons*, carry positive charges. Each neutral atom has as many protons in its nucleus as there are planetary electrons flying around it. The total charge of the atom is neutral because the positive charge of the protons is balanced by the negative charge of the electrons. We also find in the nucleus particles without any electrical charge, which are called *neutrons*. The nucleus makes up the largest part of the atom by weight.

You may be interested in knowing the electron arrangement of

some of the elements we will encounter in radio. Neon gas has 10 planetary electrons arranged in two layers (see Fig. 10). Copper has 29 planetary electrons that fly around the nucleus in four layers. The inner layer has two electrons, the next layer eight, the third layer eighteen, and the outer layer only one.

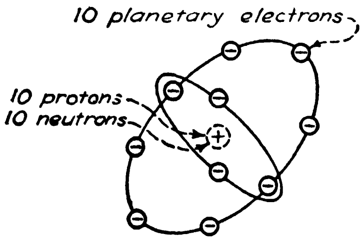


FIG. 10. This shows the arrangement of the planetary electrons, the protons, and the neutrons in an atom of neon gas.

What have these tiny electron charges to do with your study of radio?

Circuits are electron pathways. Metals act as a pathway for the flow of the tiny electron charges we call *electricity*. Examine the circuit of the radio tube shown in Fig. 11. A *circuit*, as shown in radio and electricity, is a completed electrical pathway. In Fig. 11, which shows the filament-heating circuit of a vacuum tube, we find a dry cell that supplies the electricity, a vacuum tube, the wiring to the different terminals, and a tube socket into which the tube is plugged. Note that this circuit forms a complete pathway for the electricity to flow from the dry cell, through the tube filament, through the wiring, and back again to the dry cell. In radio this is known as a *filament circuit*. For the present, we will think of the tube simply as an electric-light bulb, the dry cell as a source of electricity, and the wires as a path over which the electricity travels.

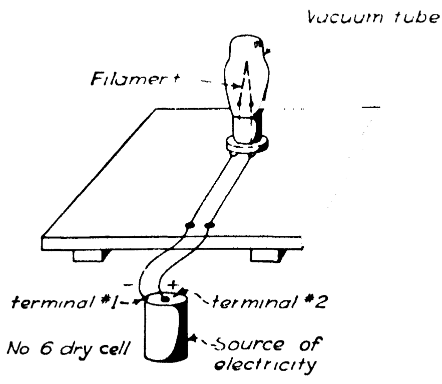


FIG. 11. This is the filament-heating circuit of a vacuum tube. Only the filament is shown in this tube. This circuit is the pathway for the electricity from the dry cell to the filament, or the heater, of the tube. The hot filament helps provide a supply of electrons for your experiments.

Metals are used in a radio circuit. What chemical elements do we find in this circuit? The wires that carry the current of electricity are made of copper, and the tube filament is made of tungsten (sometimes called *wolfram*) or of a special metallic alloy.

You will notice that the whole pathway, from the dry cell through the circuit and back to the dry cell, is metal. The connecting wires are made of copper because electricity flows easily through it. We say that copper is a good *conductor*, or a good carrier of electricity.

You also find that the tube *prongs*, or *pins*, and the tube socket have metal parts made of brass, an alloy of copper and zinc. You will find much copper, brass, and aluminum used in the different parts of radio circuits.

Why are metals good conductors of electricity? When you examine the diagrams of the atoms of metals that are good conductors of electricity, you find that they show few electrons in their outer layer. Silver, which is the best conductor of electricity, has but one electron in its outer layer. The electrons in its layers are arranged in this order: 2-8-18-18-1. Copper, nearly as good a conductor as silver, has one planetary electron in its outer layer. Aluminum, which has three planetary electrons in its outer layer, is a fairly good conductor.

Silver, copper, and aluminum, when compared to some other elements, are good conductors of electricity, because the electrons in the outer layer are easily shifted along from atom to atom when electrical force (*voltage*) from a battery or generator is applied to the wire.

Electricity is a continuous drift of electrons. If you could enormously magnify a piece of copper wire, you would see that it is composed of a myriad of copper atoms. Looking more closely, you would see the planetary electrons in each atom whirling madly about their own nucleus.

But when you touch the two wire ends of the circuit to the terminals of a dry cell, a different activity takes place. You now see the electrons driven away from the outer layer of their atoms into the space between the fixed atoms. These free electrons dart about at amazing speed in seemingly aimless paths. Watch the erratic travel of a single free electron. When it nears another free electron, it veers sharply away. Both electrons repel each other, because electrons are negative. A fundamental law of electricity states that similar charges repel each other while unlike charges attract each other. After wandering for a time, the free electron reattaches (re-attaches) itself to an atom that has become positive

by losing an electron from its outer orbit. (The positive atom attracts the electron, which is negative.)

Then, glancing along the wire, you see that many free electrons have been released from their atoms and are darting about in the space between the atoms. You note that the electrons seem to be flowing along the wire in the same direction. This flow of free electrons along the wire in the space between the atoms is what we think of as a flow of electricity or a flow of electric current.

When you touch the end of the two wires of the circuit to the terminals of the dry cell, the atoms throughout the circuit are affected almost instantly. The effect travels through the circuit with almost the speed of light (186,000 miles per second). This does not mean that any one electron or group of electrons actually travels all the way around the circuit. The circuit behaves, however, just as though a group of electrons did rush out of one cell terminal, through the circuit, and into the other dry cell terminal a fraction of a second later.

If you were to watch an individual electron, you would see that it does not move very far before it is recaptured farther along the circuit by another atom from which an electron has escaped. Thus, each electron moves along, jostling or repelling the ones ahead of it and causing a general flow of electrons around the circuit. Since all electrons are exactly alike, it makes little difference whether the ones you see coming out of the circuit are really the same ones that entered it a moment before. It is this fact that allows us to talk about the flow of electrons, or the flow of current, just as we talk about water flowing through a pipe, even though we know that electrons don't actually flow like water.

Electrical pressure causes the current to flow. The dry cell to which you attach the ends of the two wires of the circuit causes the flow of electrons. The dry cell acts like a pump, setting up the voltage, or force, that causes electrons to leave their atoms and flow along the wire. The direction of the electron flow can be changed by reversing the connections to the dry cell as shown in Fig. 12. The action of the chemicals on the zinc in the cell causes the electrons to flow along the circuit. One terminal of the dry cell is attached to the zinc shell, which encloses these chemicals. The chemical action causes free electrons to crowd onto the zinc.

The zinc terminal, with a surplus of free electrons, is said to be *negatively charged*, or *negative*.

The other terminal, the central connection of the dry cell, is attached to a carbon rod. Free electrons are drawn from the carbon. The carbon atoms, as a result, have fewer planetary electrons, and the carbon is said to be *positively charged*, or *positive*.

When you connected the ends of the circuit to the two dry-cell terminals, free electrons were forced from the negative terminal to the wire, and free electrons were drawn from the wire at the positive terminal. This set up an outward force on the electrons of the wire at the negative terminal and a pulling force on the electrons at the positive terminal. The difference of pressure between the ends of the wires of the circuit is often called a *voltage difference*. We generally say that a voltage is *set up* across the ends of the circuit.

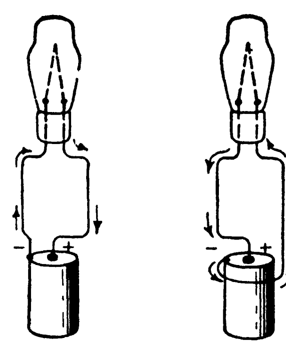


FIG. 12. You can change the direction of electron flow through a circuit by reversing the wires where they connect to the dry cell.

Voltage, the electrical force exerted by the dry cell, forces the free electrons to flow along the wire. If the voltage of the dry cell is great (or high), it will force many electrons off the atoms and a strong current will flow. If the voltage is weak (or low), few electrons are set free and a weak current will flow. You will learn later how to know accurately how much current will flow at different voltages.

What are some sources of voltage? The familiar, large No. 6 dry cell, the common flashlight cell, the tiny pen-light cell, the storage battery, the A battery, and the B battery used in portable radios all are sources of electricity, or, more properly, are sources of electrical force and current. Electricity is also generated by rotary machines, such as the generator on your car, or the huge generators at the power stations in the mountains where water power is plentiful, or the steam-driven generators at the powerhouse in your city.

Questions

1. What is the difference between direct current and alternating current?
2. Distinguish between the following terms: element, molecule, atom, electron, nucleus, proton.

3. What is an electrical circuit?

4. This exercise will check your ability to estimate the conductivity of an element by means of the number of electrons in its outer layer. Look in a chemistry textbook to find the number of electrons in the outer layers of the atoms of the following elements: sulfur, iron, carbon, nitrogen, zinc, tungsten, lead, oxygen, phosphorus, and arsenic. Now decide whether each is a good, fair, or poor conductor. Next, check your decisions by looking up the conductivity of the elements in a conductivity table.

5. When a current is flowing from a battery through a lamp, are any electrons likely to make a complete trip from the battery through the lamp and back to the battery again?

PART 2: HOW VOLTAGE, CURRENT, AND RESISTANCE ARE MEASURED

What words are used to describe electrical force? A radioman begins to change from a crude experimenter into an efficient workman when he learns to measure electric currents and voltages in the different parts of the circuit he is handling. He can then substitute accurate knowledge for guesswork.

You now have an idea of what electricity is. But in order to discuss it intelligently, you need to know the new words that describe accurately the voltage existing between the ends of the circuit, the quantity of free electrons that flow in each second as a result of this voltage, and the ease with which free electrons can move through the different metals of which the circuit wires are made. You need these words to describe and discuss the operating conditions in the circuit. This information is essential to an accurate understanding of what goes on in the radio circuit.

Consider electricity at rest and in motion. Electricity that collects on the surfaces of an automobile or truck is generated by the friction of the rubber tires on the road. The friction separates electrons from the atoms of the rubber and the road surface and deposits them on the metal car or truck body. These collected electrons are known as *static electricity*. The word *static* means *still*. The many free electrons stored on a truck body may build up a considerable difference in voltage between the truck and ground. When the driver steps from the truck, the stored electrons on the truck body try to get back to the earth through the driver's body and this may give him a noticeable shock.

You may feel this effect when you drive your car up to the gatekeeper at a toll bridge. Unless the metal frame of your car touches a wire set in the pavement to remove the accumulated

electrons, both you and the toll collector may receive a shock when you hand him a coin, as the electrons flow through you to the collector's hand and on to the earth. The moment the stored electrons rush from the metal of the car or truck to the earth, they become a current of *dynamic electricity*, or electrons in motion. In discussing radio circuits, we shall deal with both static electricity and dynamic electricity.

Voltage is the name for electrical pressure. As the driver stepped down from his truck, he probably remarked about the strength of the shock he received. On a cold, dry day this shock might be strong enough to "knock him flat." On another day he may hardly have felt the shock. Such expressions to describe the voltage resulting from the storage of electrons is useless for radio purposes. You can test the amount of voltage built up at various parts of the circuit by touching bare metal parts, but it usually is not practical or safe to do so.

The word *voltage* is used to describe the force, or effect, which causes electrons to flow through the circuit. The voltage between the truck and the earth can be measured by using suitable instruments. The truck driver would have been more accurate if he had said that he received a shock of several thousand volts. You will learn how to use meters to measure voltages in a later chapter.

What are volts, amperes, and ohms? You will need three words, or electrical terms, to describe the results of electrical measurements. The unit you use to measure voltage is called the *volt*.

A flashlight cell produces a voltage of $1\frac{1}{2}$ volts, a B battery a voltage of 45 volts. Many house lighting circuits operate at about 115 volts. You can seldom feel a shock when the voltage is less than 50 or 75 volts. This is because your skin has a fairly high resistance. Moist skin will receive shocks at lower voltage than dry skin.

Caution. Voltages from the 115-volt lighting circuit can cause dangerous shocks. Avoid touching the metal parts of such circuits.

Current is the amount of electron flow in a given time. When you connected a circuit to the terminals of the dry cell, free electrons began flowing around the circuit. This is called a *flow of current.* How many electrons are flowing through the circuit?

How rapidly are they flowing? How many flow through the circuit in 1 second? You can find the answers to these questions by using suitable tables or an instrument called an *ammeter.*

The word *current* is commonly used to refer to the quantity of electrons that are set free by the voltage in 1 second. A current of electrons flowed from the dry cell through the filament of the tube and the rheostat in the filament circuit. A current of electrons flowed from the truck to the earth through the driver's body. In each case it was impractical to count the number of free electrons that made up this current. It is inaccurate to describe the strength of the shock by the driver's reaction. Instead, you use an ammeter in which the magnetic effect caused by the flow of free electrons is made to move a meter hand. This instrument gives a sufficiently accurate estimate of the combined total effect of billions and billions of flowing electrons. *Weak current* is said to flow when relatively few free electrons flow through the wire each second; *strong current* is said to flow when many electrons flow through the wire in 1 second.

The *ampere* is the unit of current flow, or electron flow. It represents a flow of about 6.3 billion billion electrons in 1 second. A current of about $\frac{1}{3}$ ampere will light a 40-watt lamp of the familiar type we use in our homes. A 100-watt lamp requires almost 1 ampere. A 1000-watt electric toaster needs about $8\frac{1}{2}$ amperes (see Fig. 13).

Resistance expresses the opposition to the flow of electrons. Would it be easier for the free electrons to reach the earth through the truck driver's body or through a metal wire? You will probably answer correctly that metal would conduct the electrons more easily. How can you describe this difference in the case of conducting electrons? In electricity and radio, the word *resistance* is used to describe the ease of flow or the opposition to flow of free electrons through different electrical pathways, or conductors. You found that free electrons are able to flow easily through the metals silver, copper, and aluminum—all good conductors. But the flow moves with extreme difficulty through materials such as glass, porcelain, wood, Bakelite, etc. These substances are called *insulators.*

What causes resistance? The atoms of some materials, such as carbon and iron, and the atoms of mixtures, or compounds,

such as glass, porcelain, and certain alloys, are so arranged that it is difficult to dislodge any free electrons when a voltage is applied to the material. Such materials are said to have *high resistance.* Bakelite, glass, steatite, and mica have very high resistance, so that little or no current flows through them at voltages ordinarily used in radio circuits. Copper, silver, and aluminum have low resistance and are widely used as conductors in radio circuits to carry the electron flow you know as electric current from one part of a radio set to another.

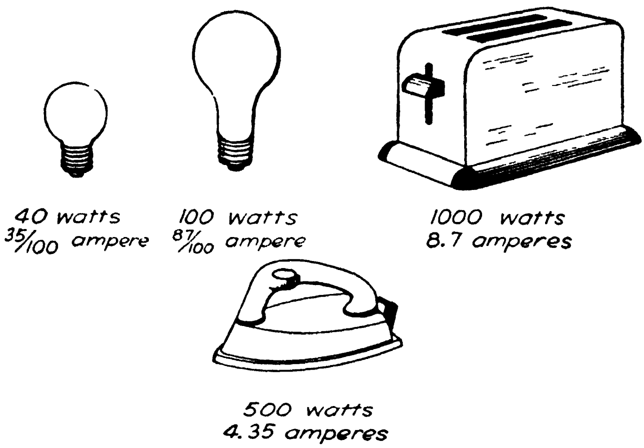


FIG. 13. Note the amount of current in amperes used by these familiar electrical appliances. Few radio tubes or parts use even a small fraction of the current used by an ordinary light globe.

The *ohm* is the unit of resistance. It was named in honor of the German scientist, G. S. Ohm, who lived from 1787 to 1854. A No. 40 copper wire 1 foot long has a resistance of approximately 1 ohm. This wire is as fine as a human hair. It is used in the coils of earphones, in choke coils, and in some audio transformers.

Number 14 copper wire, used to wire houses, has a resistance of 2.5 ohms per 1000 feet of length. One foot of wire has 0.0025 ohm resistance; No. 24 copper magnet wire has a resistance of 25.6 ohms per 1000 feet. The tungsten wire filament of a typical battery type of radio tube may have a resistance of about 20 ohms when hot. The filament of a 100-watt light has a resistance of 121 ohms, the 1000-watt lamp a resistance of 12.1 ohms.

Resistance wires made of German silver, Nichrome, or Advance wire (trade names of resistance alloys) are used to control the flow

of current in different parts of the radio circuit. Resistance parts, made of a metal or wire, are often connected in a circuit. When you examine the wiring under the chassis of a radio set, you see many small round rod-shaped parts with colored markings. These parts are fixed resistors made of pressed carbon (see Fig. 14). The purpose of connecting a resistor in a circuit is to reduce the flow of current to the desired amount in that part of the circuit.

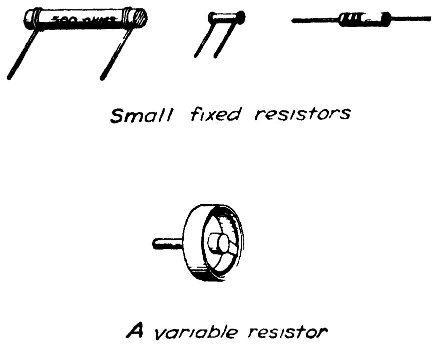


FIG. 14. Above are shown several common forms of fixed and variable resistors.

Resistance wire is sometimes wound on a form and equipped with a sliding contact, to be used as a volume control or as a

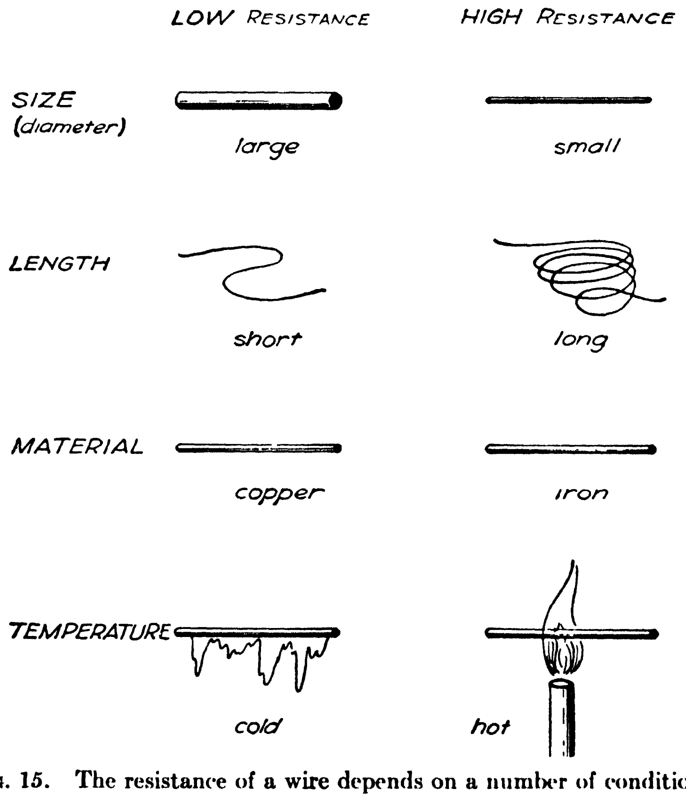


FIG. 15. The resistance of a wire depends on a number of conditions.

rheostat. Resistors with sliding contacts are called *variable resistors*. In some experiments, a rheostat is connected in the circuit of a tube to adjust the amount of current flowing through the filament.

Resistance of a wire depends on size, length, material, and temperature. The resistance of a wire depends upon its size (its diameter), its length, the material of which it is made, and its temperature (see Fig. 15). If you measure the resistance of several pieces of copper wire, you will find that the small-diameter wire has more resistance than a large wire of the same length. You will also find that a long wire has more resistance than a short wire of the same diameter. One hundred feet of No. 24 wire will have 10 times more resistance than will 10 feet of the same size wire. Also, a piece of iron wire will have more resistance than a copper or a silver wire of the same length and size.

Heat affects the resistance of a wire because it speeds up the vibrations of the atoms in the wire. The resistance increases as the wire gets hotter. However, the resistance of wires made of some alloys remains nearly the same as the wires get hotter, and the resistance of carbon and glass becomes less when they are heated.

Questions

1. What is the difference between static and dynamic electricity? Give several illustrations of each type.

2. Define the terms *volt*, *ampere*, and *ohm*. See if you can find analogies for these terms when you consider water flowing through a pipe.

3. The statement is made that the resistance of a wire depends upon its size, length, material, and temperature. Compare the flow of water through a pipe with the flow of electrons along a circuit.

Technical Terms

ampere—The unit used in measuring the *quantity* of electric current.

atom—The smallest division of an element of matter. The atom was once thought to be the smallest possible part of matter, but now it is known that the atom is made up of electrons, protons, and neutrons.

charge—A term used to indicate that an object has too many or too few electrons. If too many, the object has a negative charge; if too few, it has a positive charge.

chassis—The metal pan, or base, on which are mounted the tubes, condensers, transformer, and other parts of a radio receiving set.

circuit—A completed electrical pathway.

•**conductor**—A carrier of electricity—a substance which will permit electrons to flow through it. Wires and metals are, in general, good conductors.

•**current**—A flow of electrons through a conductor. There are two types of electric current—*alternating current* and *direct current*. In alternating current, the electron flow changes direction at regular intervals. The alternating current in the home light and power wires changes direction 120 times per second; therefore, it is called a 60-cycle alternating current. You may have a 50- or even a 25-cycle current supply in your community. In direct current, the flow of electrons is continuous and in one direction only.

dynamic electricity—Moving or flowing electrons (see *current* and *static electricity*).

electron—A unit negative particle of electricity. It is $\frac{1}{1815}$ as heavy as a hydrogen atom.

electron flow—Free electrons traveling aimlessly, darting about in the spaces between the atoms of a copper wire or other conductor. When a battery or generator is connected to the two ends of the conductor, the electrons are forced to flow in one direction (see *current*).

element—A substance which cannot be separated by ordinary chemical means into substances different from itself. Examples: copper, tin, iron, aluminum, silver. (Brass is an alloy of copper and zinc.)

•**insulator**—A relatively poor conductor of electricity. Examples: glass, porcelain, wood.

molecule—The smallest possible particle of an element or compound that can normally exist separately. A molecule of water is composed of one atom of oxygen and two atoms of hydrogen.

motor generator—A motor-driven machine in which wires wound on a rotor are whirled past stationary coils wound on iron cores. The stator (stationary) coils are energized by a current and become magnetized. This sets up a current in the rotor coils as they whirl through the magnetic fields of the stator magnets. You may say that the machine "generates" electricity. Actually, the energy of its whirling motor is converted into electrical energy.

neutron—A unit neutral, or uncharged, particle in the nucleus of an atom.

nucleus—The heavy central part of an atom, containing one or more protons and neutrons.

•**ohm**—The unit used to measure electrical resistance. A No. 14 antenna wire 1000 feet long has 2.5 ohms of resistance.

planetary electrons—Electrons that move in orbits around the central nucleus of an atom.

proton—A unit positive electrical charge in the nucleus of an atom.

•**resistance**—The opposition to the flow of electricity offered by a substance.

static electricity—Stationary (static) electrons collected on a surface. If the electrons begin to flow, they become dynamic (current) electricity.

•**voltage, or electrical pressure**—Known technically as *potential difference* expressed in volts. *Voltage* is defined as the amount of work per unit charge in moving the charge between two points in a conductor.

This type of definition is quite technical for your present use. You will **learn** radio faster and understand the meaning of voltage better if temporarily

we use a more general term, such as *electrical pressure*, or simply *pressure*, while you are becoming acquainted with basic radio and electrical facts.

You will learn electrical and radio theory faster when it is expressed in your own words than if it is explained in the advanced language of the electrical or the radio engineer. You will acquire these terms gradually, and you will build an understanding of them through study and experience with electrical and radio equipment.

watt—The unit of power. It is found by multiplying volts times amperes.

CHAPTER 4

MAGNETISM AND DIRECT-CURRENT METERS

As you study radio circuits, you find that they include parts, such as the filament of a vacuum tube or the wire in a rheostat, in which resistance is a very important factor. In radio circuits you find many fixed resistors that are used to maintain definite values of current or voltage in different parts of the circuit. You also find coils and condensers that have resistance, which you will consider in later chapters. The resistance of these parts affects the current and voltage in a circuit. If the circuit is to operate efficiently, the voltages and currents must be accurately set.

Meters give the radioman definite facts about the voltages and currents at the tubes and at other points in the circuits of his set. Direct-current (d-c) meters used in radio work are delicate instruments that look mysterious, but they are really very simple When you examine a burned-out meter without its protecting case, you see that its principal operating parts are a magnet and a moving coil of wire. The operation of meters follows the laws of magnetism, which are easy to discover and to understand.

You will learn the following things in this chapter:

Part 1: How Meters Commonly Used in Radio Work Are Constructed
Part 2: On What Principles Do Simple Magnets Work?
Part 3: Why a Moving Coil Is Used
Part 4: What Makes the Meter Coil Turn?
Part 5: How the Meter Measures the Current Flowing in a Circuit
Part 6: How to Use the Milliammeter in a Radio Circuit
Part 7: How a Meter Measures Voltage
Part 8: How the Voltmeter Is Used in a Circuit

Symbols are the shorthand of radio. As you read and use this book, you will look at many drawings and photographs of radio sets, of radio parts, and of radio circuits. You will spend considerable time drawing these circuits, because this is a good way to learn them.

You will soon find that you can use symbols that look like coils or condensers much more easily than you can draw pictures of them, unless you are an accomplished artist.

As you read each chapter, you will find the symbols introduced in that chapter shown in a separate diagram, so that you will recognize them when you first meet them in your reading. The first group of symbols is shown in Fig. 16.

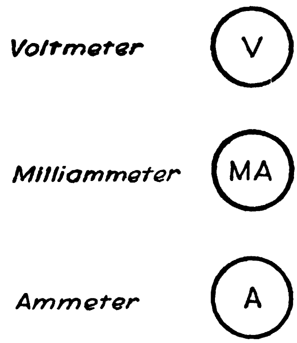


FIG. 16. Symbols used in this chapter.

PART 1: HOW METERS COMMONLY USED IN RADIO WORK ARE CONSTRUCTED

Examine a standard meter. Examine a burned-out direct-current meter. This is a fine way to get acquainted with a meter and to learn to handle it without damaging its delicate moving parts. Since most meters of good quality use the D'Arsonval principle of a permanent magnet and a moving coil, you will begin your study with such a meter.

First, examine the meter in its protective Bakelite or metal case. Note that one binding post mounted on it is marked + (or positive). Note the screw in the face for adjusting the meter hand to zero.

Remove the case and examine the meter movement. The *movement* consists of a magnet and a moving coil. The magnet will attract steel, as you will find if you touch it with your knife or a screw driver. It is made of a special steel carefully selected and heat-treated so that the meter readings will remain the same as the meter ages.

Why is the solid inner core used? Since magnetism passes more readily through iron than through air, a small, cylindrical iron core is fastened in the space between the curved ends of the poles (see Fig. 17). A narrow space is left between the core and the poles for movement of the coil.

What is the meter coil? A tiny coil, wound on a light metal form, swings back and forth in the space between the curved ends of the magnet and the round iron core. Examine it closely, and you will see the turns of wire with which it is wound (see Fig. 18).

Very fine wire is used so that the tiny coil can consist of many

turns. The space between the core ends and the round inner core can then be very small, and the meter will be sensitive to weak currents.

Two tiny pointed pivots are cemented to the coil. The hardened ends of the pivots rest in glass jewels or sapphire bearings so that the coil will swing freely with a minimum of friction. Two tiny spiral springs fastened to the pivot pins keep the coil in the zero

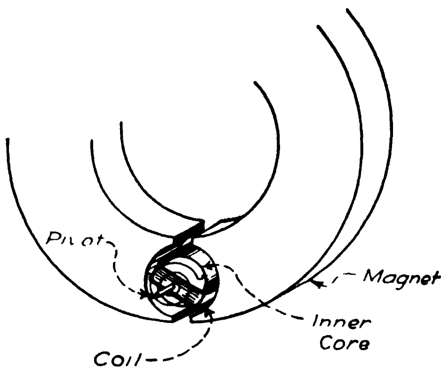


FIG. 17. This diagram shows the solid, round, inner core in place inside of the meter coil.

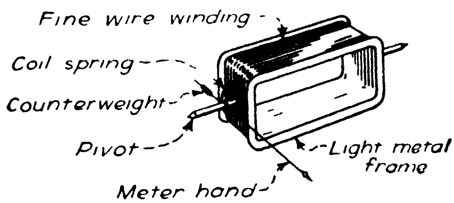


FIG. 18. This is an enlarged view of the moving coil.

position when no current is flowing through it. If you trace the path of the circuit through the meter, you will find that it comes into the meter at one binding post and passes through one spiral spring, through the coil, and out through the other spiral spring to another binding post.

What is the meter hand? The meter hand is a tiny aluminum tube attached to the moving coil. It is balanced by a tiny weight placed on a short extension of the hand, on the opposite side of the bearing from the pointer.

Now learn how a meter works. Since its operation depends on the action of magnetic fields, you will learn first about magnets and magnetic fields.

PART 2: ON WHAT PRINCIPLES DO SIMPLE MAGNETS WORK?

What are magnets? Two kinds of magnets are used in radio permanent and temporary. A temporary magnet holds its magnetism for only a short time. You will learn more about this kind of magnet when you study transformers, choke coils, and generators.

Permanent magnets retain their magnetism for long periods of time. They are used in meters, in some kinds of generators, and in some loudspeakers. But what makes one a permanent and one a temporary magnet?

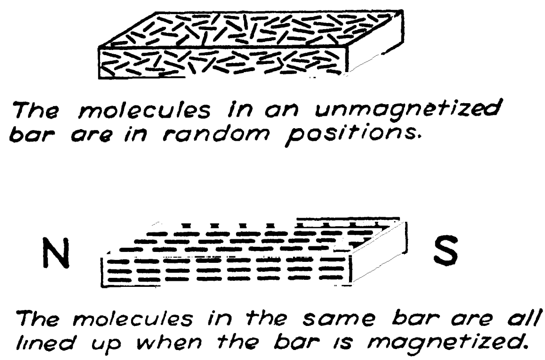


FIG. 19. This shows the difference in the arrangement of the molecules in a bar of iron before and after being magnetized.

What is the difference between permanent and temporary magnets? Only certain metals can be magnetized. These metals generally contain iron. They are called *ferrous* or *ironlike* metals. You cannot pick up brass, copper, aluminum, or other nonferrous (non-ferrous) metals with a magnet. Such metals are nonmagnetic (non-magnetic).

An unmagnetized bar of iron is made up of a myriad of molecules in random positions. Each molecule is actually a tiny magnet, with a north-seeking pole and a south-seeking pole. But because the molecules are in random positions in the bar, the bar itself is not magnetized. Strangely enough, when the iron bar is magnetized, the molecules are all aligned in the same direction to produce a north-seeking (or north) magnetic pole at one end of the bar and a south-seeking (or south) magnetic pole at the other end (see Fig. 19).

If the bar is of hard steel, the molecules are permanently lined up when it is magnetized and the bar is called a *permanent magnet.* But if soft steel or soft iron, such as a tack or a brad, is magnetized, most of the molecules return to their original position when the magnetizing force is removed. The steel then is called a *temporary magnet.*

You can tell when a bar is magnetized, because it will pick up, or attract, pieces of iron. You can use a magnet to sort iron and brass machine screws and nuts such as those used in building a radio set. It will pick up the iron pieces and leave the brass ones undisturbed. Steel screw drivers become magnetized after touching a magnet.

In radio work you must know something about the force we call *magnetism* so that you can use magnets intelligently in radio equipment. First, you will study the magnetic force around a bar magnet.

What is a field of force? We believe that magnetic force is transferred from molecule to molecule through the length of the steel bar. But, outside of the bar, the force spreads outward from the ends of the bar in a definite pattern, or *field of force.*

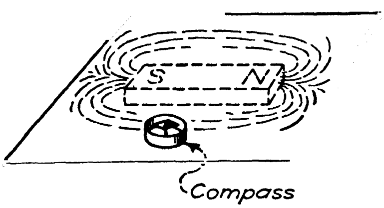


FIG. 20. Scatter iron filings over a piece of paper held over a bar magnet or use a compass as shown to see the shape of the field of the magnet.

You can study the shape of the field by using a small compass. Move it to a point near the magnet, and you can watch the needle swing until it points along the direction of the force around the magnet. A way to see the pattern more clearly is to scatter soft iron filings on a piece of paper and hold it over the magnet, as shown in Fig. 20. When you jar the edge of the paper, the filings arrange themselves in groups that form lines from one end of the bar to the other. These trace out the pattern of the field of magnetic force around the bar.

The paths of the magnetic force from one magnet pole to the other are called *lines of force.* The force exists more or less uniformly all around the bar, but the iron filings cling together to form lines which show the direction of these lines of force between the two poles.

How can you show that the magnet has north and south poles? The ends of a bar magnet are called *poles.* Hang the bar by a thread tied at its center; the bar will swing so that the ends point north and south. The end that points north is the north-seeking (or north) pole, and the other end the south-seeking (or south) pole.

How does the strength of a magnetic field vary with distance from the magnet? Hold the magnet near a pile of tiny steel brads or tacks. You find that the magnet lifts many brads when it is close to them, but when it is held farther away, they are unaffected. Precise experiments prove that the force is strong near the magnet but weakens rapidly as the distance from the magnet becomes greater.

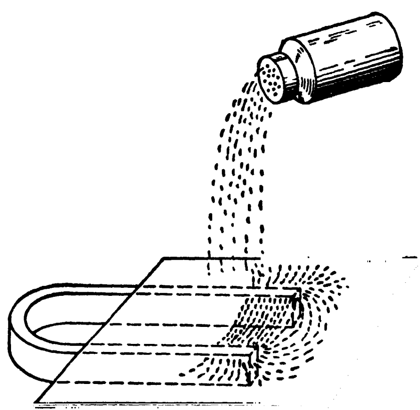


FIG. 21. Scatter iron filings on the paper to see the shape of the field of the horseshoe magnet.

Examine the magnetic field of a horseshoe magnet. The meter coil must move in a strong magnetic field. A magnetic field can be obtained by forming the iron bar magnet into a horseshoe, or a round loop with a small space between the ends. The field will then be very strong between the pole ends.

You can examine the pattern of the magnetic field of force between the poles of the horseshoe magnet by the same methods you used with the bar magnet. Sprinkle iron filings on a piece of paper placed over the magnet. Tap the edge of the paper lightly so that the filings will be distributed evenly. Note that the magnetic force is most intense between the poles and that the force spreads out between the ends of the magnet (see Fig. 21).

You can make a permanent diagram of this magnetic field by placing a piece of blueprint or any other light-sensitive paper over the magnet. After the filings are in position, expose the paper to full sunlight for 30 seconds to 1 minute. When the paper is developed, it will show a beautiful, permanent silhouette of the filings representing the shape of the magnetic field.

Hold a small compass near each end of the magnet to find its

north and south poles. The north pole of the magnet will attract the south-seeking pole of the compass (see Fig. 22).

Draw arrows on the lines of force on your diagram. Mark the north and south poles. You will use this information later.

For convenience, we assume that the magnetic lines of force leave the north pole and go to the south pole of a magnet.

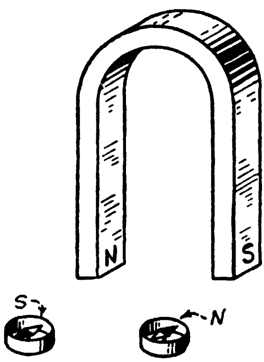


FIG. 22. Which is the north pole and which is the south pole? Hold a compass near each pole and you can decide its polarity by the way the compass needle points.

Rule. The magnetic lines of force leave a magnet at its north-seeking pole and reenter (re-enter) the south-seeking pole.

Examine the magnet in a meter. Examine the permanent magnets in several meters. In some meters, the magnet is shaped like a horseshoe with attached pole pieces, while in others it may be shaped as an open-ended circle. A circular space is cut in the ends of the poles to leave space for the tiny movable coil. The ends of the poles are close together.

Why do the ends of the magnet in a meter have little space between them? The magnetic field between the poles must be very strong if the meter is to be sensitive enough to measure weak currents. The coil of a meter for radio use must move when a very small amount of current flows through it. The meter must use only a small amount of the current which flows in the part of the radio circuit you are studying. A meter that needs much current will sometimes give worthless indications and may throw off the operation of the circuit.

The field will be strong if the space between the ends of the poles and the central core is made very small. The magnetism then has a narrow air space to cross, and so the field in this space will be intensely strong.

How can the field between meter poles be made uniform and strong? You can examine the shape of the field between the poles from a burned-out meter by sprinkling iron filings on a paper placed over the magnet. This field can be examined more easily, however, if you make an enlarged model of the meter magnet and the central core piece. For this, use a horseshoe

magnet and two pieces of steel cut from an old set chassis shaped like pole pieces. Sprinkle iron filings over the model, and observe that they group themselves *unevenly* between the ends of the pole pieces. The filings show the magnetic field to be strongest where the pole ends are close together. There are few filings in the center where the poles are far apart. Here the magnetism is weak because air is a poor pathway for the magnetic field. The field is weakest where the distance between the poles is greatest.

Such an uneven field is poor for use in a meter, because the calibrating marks of the scale on the meter face would have to be unevenly spaced. This makes the meter hard to read.

If we make the magnetic field uniform, the marks on the scale will be the same distance apart. The field will be uniform if the air space between the ends of the poles is made the same. In an actual meter, this is accomplished by placing a round piece of iron in the space between the pole ends to form a pathway for the magnetism (see Fig. 17).

Now again examine with iron filings the magnetic field of your model meter, this time using a round, flat piece of steel between the poles. When you tap the paper, the iron filings distribute themselves evenly in the space left between the curved ends of the poles and the inner core. This shows that the field of force between the pole pieces is uniform and stronger. The calibrating marks on the meter scale can now be evenly spaced.

Questions

1. Is the needle of a compass a permanent or a temporary magnet?
2. Which will lift more, a horseshoe magnet or one end of a bar magnet?

PART 3: WHY A MOVING COIL IS USED

Before you can understand why the tiny coil, mounted on pivots, will turn in the space between the curved ends of the magnet and the round inner core, you must learn how a magnetic field is formed around the coil when a current of electricity flows through it. You must also learn how this field is used in the meter to measure electrical current. First you will study how the field is formed around the wire and around a coil; then you will learn how this field makes the coil turn.

Examine the magnetic field around a wire. Think of an electric current as the flow of free electrons through the wire. When

these electrons move, they set up around the wire a field of force similar to the field around a magnet. You can study such a field of force by passing the current from a storage battery through a short piece of insulated wire and using iron filings to show the field pattern. When electricity flows through the wire, a weak magnetic field is set up around the wire. To examine the field, pass the wire through a piece of cardboard as shown in Fig. 23; then sprinkle iron filings on the cardboard around the wire. Tap the

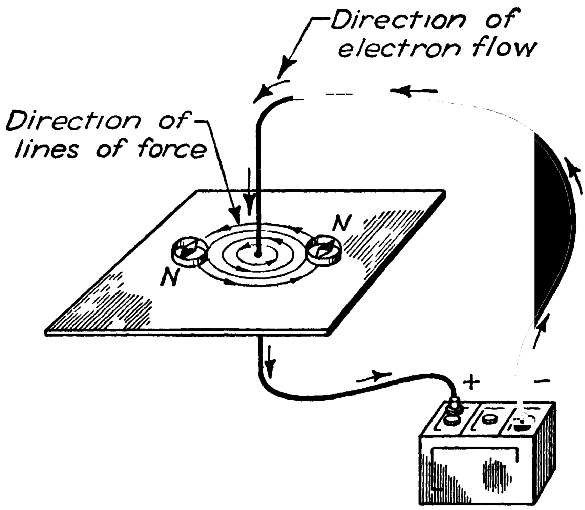


FIG. 23. When electricity flows through the wire it sets up a magnetic field around the wire. You can study the direction of the lines of force with small compasses.

cardboard until the filings form a pattern. Work quickly because the wire will heat rapidly. (You can also study the field by using small compasses.)

You can get a stronger effect if you wrap this wire into a coil of several turns, as you will see later.

What is the direction of electron and current flow? Sooner or later as you progress in your study of radio, you will find that many people will speak of current flowing in the opposite direction to that of electrons. This is because of a curious accident. Benjamin Franklin believed that electricity flowed from a place where there was a surplus of electricity to a place where there was too little, but he thought electricity was made up of *positive* electric particles instead of *negative* electrons. He explained the

current as flowing in the direction opposite to electron flow. If he had known as much about it then as we do now, he would have saved us much trouble. Most people who studied physics before the Second World War and most texts written before this war described current flow as Franklin did. In this book we have adopted the modern viewpoint and speak only in terms of electron flow.

How is the left-hand rule used? The left-hand rule is handy to use to find the direction of the lines of force around a wire

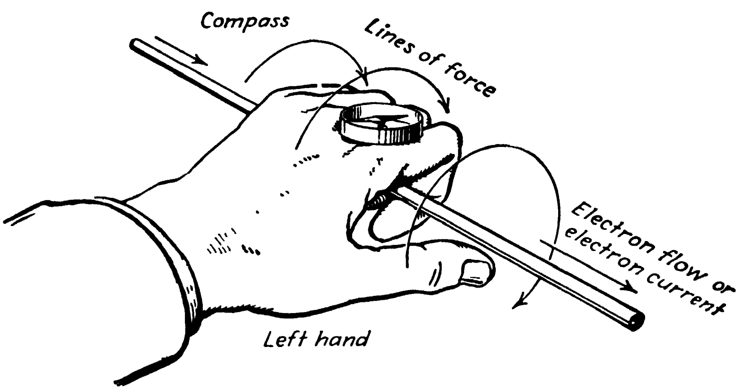


FIG. 24. The left-hand rule. Grasp the wire in the left hand. The thumb must point in the direction of *electron flow*. The fingers then point in the direction of the lines of force.

when you know the direction of electron flow. It shows the direction the compass needle will point when held near the wire.

Rule. If you grasp the wire in your left hand with your fingers around the wire and your thumb pointing in the direction of the electron flow, your fingers will point in the direction in which the north end of the compass needle will point when brought near the wire. Try this. Prove the rule by holding a compass near the wire, as shown in Fig. 24.

This rule can be used to find the direction of the electron flow when you know the direction of the lines of force. The wire is grasped in the same way, with the fingers of the left hand around the wire, pointing in the direction of the lines of force. The thumb will then point in the direction of the electron flow.

A coil carrying current has a strong magnetic field. Wrap 50 turns of No. 28 insulated wire into a well-bunched coil about

$\frac{1}{2}$ inch inside diameter (see Fig. 25). Touch the ends of the wire to the terminals of a storage battery. Show how strong the magnetic field of the coil is by using it to pick up brads or iron filings. This coil, made into a magnet by a current flowing through it, is

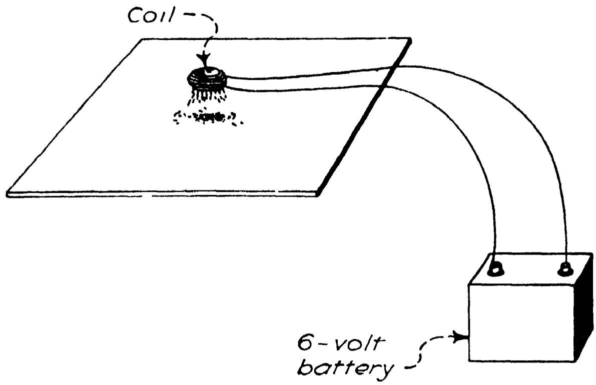


FIG. 25. A small 50-turn coil will pick up iron filings or small brads when the ends of the wires are touched to the terminals of the storage battery. Current flowing through the coil makes it an electromagnet.

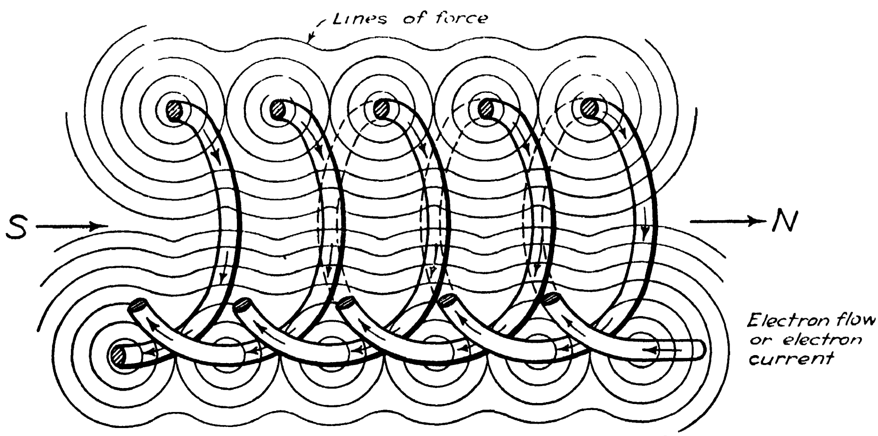


FIG. 26. This enlarged view of several loops or turns of the coil shown in Fig. 25 shows a section of the lines of force around each turn. Note how the magnetic force blends together around the turns.

called an *electromagnet* (electro-magnet). But why does a coil of wire have more magnetic strength than the same wire laid out straight?

In Fig. 26 are pictured in enlarged form several loops of the coil you just made. Note that the magnetic field of each loop inside

of the coil adds to the field from the next loop. This makes a strong field inside the coil.

One end of the coil is a north pole and the other a south pole. A compass held at each end of the coil shows that one end is a north pole and the other a south pole. You can also find these poles by using a slightly different version of the left-hand rule.

When you study magnetic coils, you are interested in the direction of electron flow and the resulting magnetic force, because they determine the north and south poles of the coil. Use the alternative form of left-hand rule.

Rule. Place the fingers around the coil, pointing in the direction of electron flow through the wire; your thumb will point to the north pole of the coil.

How can the strength of an electromagnet be increased? There are two easy ways to increase the magnetic strength of the coil. One way is to form the same wire into a small coil of many turns. The strength of the coil's magnetic field is equal to the sum of the strengths of the magnetic fields around each turn of the wire. The other way is to make a stronger current flow through the coil (see rules below). A coil through which a current flows has around and through it a magnetic field of force and acts like a bar magnet.

Now you will learn something about the factors that govern the magnetic strength of a coil. Do the following experiments:

Experiment 1. Wind about 10 turns of No. 28 insulated wire around a pencil, to form a small, compact coil. Remove the pencil and attach the ends of the wire to the storage battery, and see how many iron filings or how many wire brads the coil will pick up. Now wind a second coil of 50 turns of the same size of wire around the same pencil. The new coil, having more turns, will pick up many more wire brads or iron filings (see Fig. 27).

Experiment 2. Attach a 30-ohm rheostat in one wire of the 50-turn coil. Turn the rheostat to reduce the current flowing through the coil. You will now find that the coil picks up few brads or iron filings. Increase the current, and the coil will pick up many more brads or filings. This proves that the strength of the electromagnet also depends upon the amount of current flowing through the coil. You now have two rules for the strength of electromagnets.

Rule 1. The strength of an electromagnet depends upon the number of turns in the coil, and

Rule 2. Its strength depends upon the amount of current flowing through the coil.

These two rules are often combined by engineers in a different form. They say that the strength of the electromagnet depends on its *ampere-turns*, or the strength of the current in amperes multiplied by the number of turns on the coil.

Both of these facts are used when a meter is designed, and the meter depends upon them for its operation.

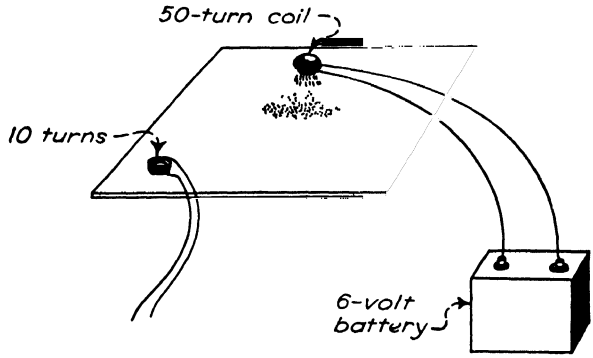


FIG. 27. Which coil will pick up more iron filings? Does the coil with few turns or does the coil with many turns have the greater magnetic effect?

How is the meter coil designed? The moving coil of a sensitive meter must be very light in weight; a heavy coil would be sluggish and slow to move. Therefore, the coil of a meter is wound on a very light metal form.

Small wire is used on the coil for two reasons: (1) because the coil must be small so that the air space between the magnets may be small, and (2) because the coil must have many turns in order to get a strong magnetic field. For a meter to be sensitive, a very small amount of current must produce the strongest possible field around the coil. From Rule 1 you find that many turns will give you a strong magnetic field.

Questions

1. What is the shape of the magnetic field around a straight wire which is carrying a current of electricity?

2. Why does a coil have a stronger magnetic field than a straight wire?

3. When you hold a compass over a wire carrying a direct current, if the north pole points away from you, is the electron flow toward your right or toward your left?

4. What two factors determine the strength of an electromagnet?

5. Two amperes are flowing through a long wire which is loosely coiled into 50 turns. If you recoiled this wire into 100 turns, how would the magnetic strength be affected? What would be the ampere-turns in each case?

PART 4: WHAT MAKES THE METER COIL TURN?

Like poles repel, and unlike poles attract. As you continue to study magnets, you learn many interesting new facts about them. You find that magnetism has much to do with radio instruments and with radio circuits. Suppose you examine in more detail the action of magnets employed in meters.

Experiment 1. Hang two horseshoe magnets by a string. Bring their north poles and then their south poles toward each other. Just as in your experiment with the horseshoe magnet and compasses, you find that the north poles repel each other and that the south poles repel each other. Now bring a north and a south pole toward each other. You find that they attract and come together (see Fig. 28).

Rule. Like poles repel and unlike poles attract.

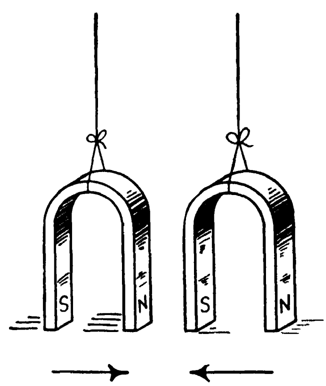


FIG. 28. This experiment shows that *unlike* poles *attract.*

The magnets will swing until unlike poles are together. The meter you are studying is simply an application of this principle of the attraction or repulsion of the poles of two magnets—one, the permanent magnet that is stationary, and the other, the coil electromagnet that is pivoted so it can turn. The north and south poles of the permanent magnet act on the poles of the coil electromagnet, which is placed in the space between the ends of the permanent magnet poles.

Experiment 2. Lay a horseshoe magnet on the table. Think of this as the permanent magnet in the meter. Hang a second permanent magnet by a thread above the first in the position shown in Fig. 29; this second magnet takes the place of the moving coil magnet in a meter. When the two magnets are brought

together, the moving magnet will turn so that the unlike poles are together. The like poles repel and the unlike poles attract, which causes the hanging magnet to turn. But how does this apply to a meter?

An electromagnetic coil will turn in a magnetic field. You can see how a coil and a magnet form a meter by doing this interesting experiment.

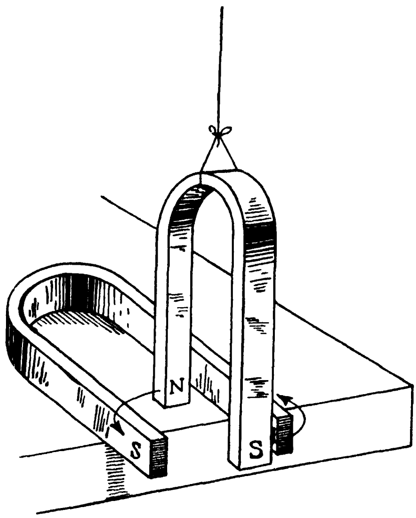


FIG. 29. The upper magnet turns or rotates for the same reason that the coil in a meter turns or rotates.

Experiment 3. Wind 50 turns of No. 28 insulated wire around your hand. Form the wire into a coil as shown in Fig. 30. Leave about 2 feet of loose wire on each end of the coil.

Step 1. Hold the loose wires so the coil hangs between the poles of a horseshoe magnet laid on the edge of the table as shown in Fig. 30.

Step 2. Now, have another student touch the ends of the wires to the terminals of a battery. When current flows through the wire, the coil rotates.

Step 3. Next, have the other student touch the ends of the wires to opposite terminals of the battery, so that the direction of current flowing through the coil is reversed. The coil then turns in the opposite direction.

Why it works. You saw that when a current flows into the meter, it passes through the coil, making it into an electromagnet. The coil then has a north and a south pole just as the permanent magnet has. Since the coil is free to move, it turns so that similar poles repel and opposite poles attract. The north pole moves toward the south pole, for example.

In the meter, the coil is mounted on glass or sapphire jewels, or bearings, so that it will turn easily. The two spiral coil springs oppose its rotation and return it to the zero position. In the next section of this chapter you will see how the turning effect of the coil, acting against the springs, can be used to measure current.

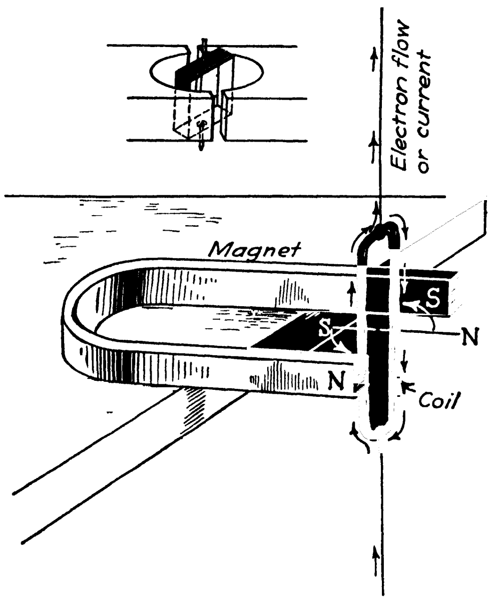


FIG. 30. Here the coil replaces the upper magnet in the experiment shown in Fig. 29. Touch the ends of the wires to a battery and watch the coil twist and rotate just as the coil in a meter will twist and rotate when a current is passed through it.

PART 5: HOW THE METER MEASURES THE CURRENT FLOWING IN A CIRCUIT

Examine a milliammeter. Because the direct-current milliammeter is simple to describe, we shall select it to explain how the coil moving between the ends of a permanent magnet can be used to measure the amount of current flowing in a circuit. A milliammeter is a meter designed to measure *very weak currents*. A *milliampere* is $\frac{1}{1000}$ of an ampere. (Milliampere is abbreviated as ma.) A meter for measuring stronger currents is called an *ammeter*.

Examine the meter diagramed in Fig. 31. Trace the current as it flows through the meter. Notice that the electron flow travels from the negative binding post, through the moving coil, and out through the positive binding post. But what happens when electricity flows through this meter?

Why it works. As the electron flow moves through the wires of the meter coil, it makes the coil into an electromagnet. The coil is held at an angle in the space between the poles of the permanent magnet by the coiled hairsprings (see Fig. 32).

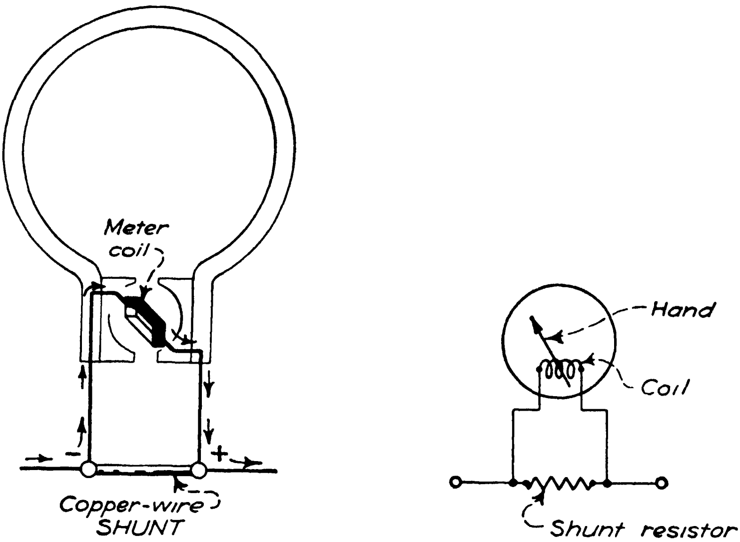


FIG. 31. This is an ammeter connection. When you want to measure heavier currents than the meter will carry, you attach a shunt across the milliammeter as shown here. The size of the shunt is selected so that it carries most of the current and the coil carries only its usual amount.

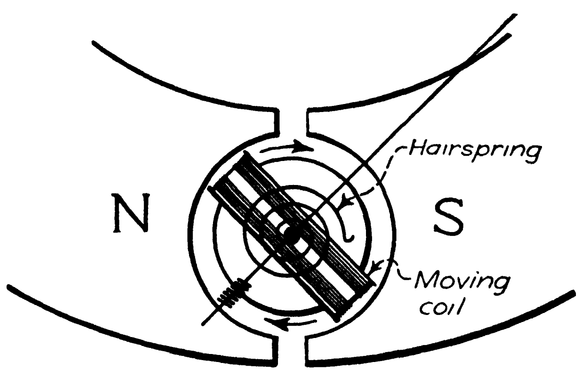


FIG. 32. The poles of the meter coil are attracted to the opposite poles of the permanent magnet when current flows. This causes the coil to turn or to rotate against the opposing force of the springs.

The magnetic fields of the coil and of the permanent magnet turn the coil. This happens because the like poles of the two magnets repel and the unlike poles attract each other. The poles of the magnetized coil are forced toward the corresponding opposite poles of the permanent magnet.

How far will the coil turn? You learned earlier in this chapter that the strength of an electromagnet depends on the strength of the current that flows through the coil. Suppose a small quantity of current causes the coil to turn against the hair spring enough to move the pointer halfway across the dial. Twice this amount of current will make the coil twice as strong a magnet and, therefore, will cause it to turn enough to move the pointer all the way across the dial, or twice as far.

PART 6: HOW TO USE THE MILLIAMMETER IN A RADIO CIRCUIT

Measure the plate current flowing through a tube. A milliammeter measures currents of a few thousandths of an ampere

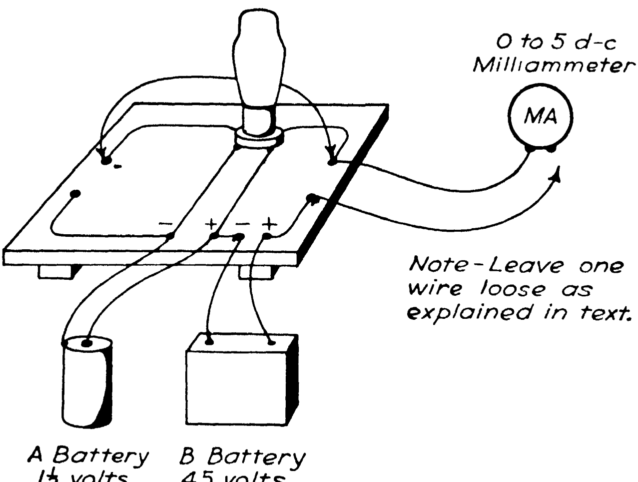


FIG. 33. Connect a milliammeter in the plate circuit as shown here. When connected in this way the meter measures the amount of current flowing through the tube from the filament to the plate.

that flow in some parts of radio circuits. You can get acquainted with this meter by making measurements of the current flowing in the plate circuit of a triode vacuum tube.

Experiment. Measure the plate current flowing through a tube.

Step 1. See Chapter 6 in order to find out how to construct and wire the circuit board shown in Fig. 33. Connect a 0 to 5 direct-current milliammeter to the circuit board as follows: Connect only one wire to the meter. Leave the other wire loose, so that it can be touched to the meter binding post to see if the

meter is correctly connected. If the meter needle moves in the wrong direction, reverse the connections to the meter.

Step 2. Turn on the filament, connect the loose wire, and current will flow through the meter. All the current that flows through the plate circuit of the tube also flows through the meter.

How can stronger currents be measured? If you want this meter to measure larger values of current, you divert some of the current through a copper wire called a *shunt*, connected as shown in Fig. 31, so as to allow only a small amount of current to flow through the meter coil. The amount of current that flows through the coil and through the shunt is determined by the relative resistances of the coil and the shunt.

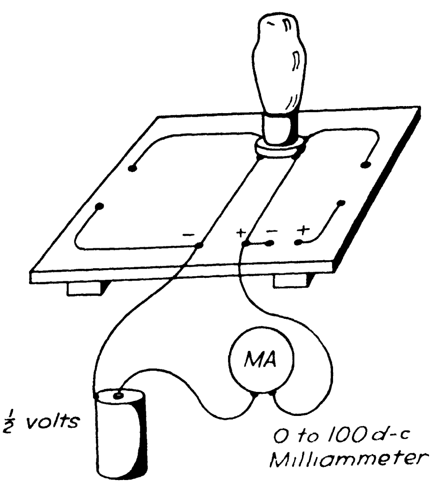


FIG. 34. *Filament* circuit of a tube. Use this circuit and its connections to measure current flowing through filament.

If you want a 0 to 1 milliampere meter to measure 0 to 10 milliamperes of current, you select a shunt that will carry 9 milliamperes of current and leave 1 milliampere for the coil. Then, when 10 milliamperes of current flow in this circuit, the meter reads 1 milliampere, or full scale.

When 5 milliamperes flow in the circuit, only $4\frac{1}{2}$ milliamperes flow through the shunt and $\frac{1}{2}$ milliampere through the coil. The meter reads half scale, or 5 milliamperes.

How can the filament current be measured? When you wish to measure the filament-heating current that flows from the A battery, you connect a meter in the filament circuit (see Fig. 34).

The kind of tube you place in the circuit in your experiment determines the range of the meter that you must use.

Look up in a tube manual, which you can obtain from a radio dealer, the value of the filament current for this tube. If you are using a 1LE3, the current will be 0.050 ampere. This is $\frac{50}{1000}$ ampere, or 50 milliamperes, so the meter you select will probably be a 0 to 100 direct-current milliammeter.

Rule. ***Whenever possible, use a meter with a range that allows the reading to come near the middle of the scale.***

Questions

1. How many milliamperes of current flow through the filament of the 1LE3 tube? (Find the filament current for the 1LE3 tube in the Condensed Data Section, pages 670–693.)

2. How many milliamperes would flow if a type-30 tube were used?

3. What range of milliammeter would be used in the plate circuit of a 1LE3 tube with 45 volts on the plate?

4. What range of milliammeter would be used in the plate circuit of a 1LE3 tube with 90 volts on the plate?

PART 7: HOW A METER MEASURES VOLTAGE

What is voltage? *Voltage* is the word used to describe the electric force that causes *free* electrons to flow through a wire or other conductor. You measure voltage between two parts of a circuit. For example, you measure the voltage across the terminals of a filament or the voltage between the filament and the plate of a tube. This voltage is referred to as the *voltage difference* or *voltage drop* between the terminals of a filament or between the filament and the plate of the tube. It is this difference in voltage, or voltage drop, that you measure with a voltmeter.

How can a meter be used to measure voltage? You can use the same meter movement, the permanent magnet, and the moving coil unit of the milliammeter to measure voltage if you change the internal connections of the meter. You now connect a resistor in series with the meter coil as shown in Fig. 35.

The value of this resistor is selected so that it permits only enough current to flow through the coil to make the meter hand move across the scale. For a 0 to 1 voltmeter, 1 volt will force enough current through the meter coil to move the meter hand all the way across the scale. In the next chapter, "Ohm's Law by Simple Mathematics and by Meters," you will learn more about the way that voltage and current work together.

When electrons flow through the coil, they make it an electromagnet and cause it to turn, as was explained when the milliammeter was discussed.

If a certain voltage forces an amount of current to flow through the coil and makes it move the hand halfway across the scale,

twice the voltage will force twice as much current through the resistor and coil and so move the hand to full scale (see Chapter 5 for an explanation).

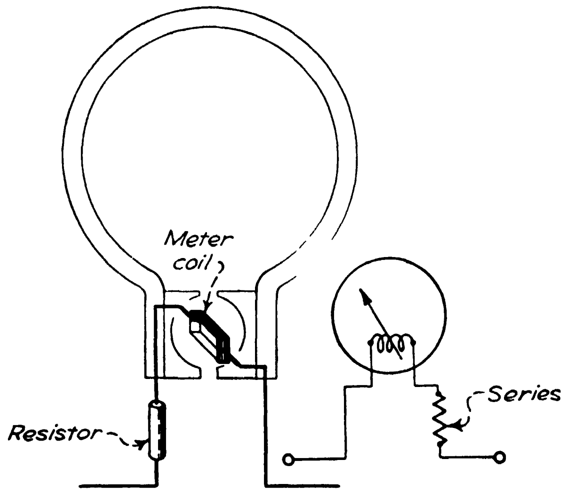


FIG. 35. This is a *voltmeter* connection. When a resistor is connected to the milliammeter as shown here the meter can be used to measure voltages.

PART 8: HOW THE VOLTMETER IS USED IN A CIRCUIT

How to measure voltages in the filament circuit. You can learn to use the voltmeter by taking some voltage readings on the filament circuit of the tube that you will use many times in later experiments. In the circuit shown in Fig. 36 there are three important parts: the filament of the tube, the wiring, and the battery for heating the filament. Disregard the resistance of the connecting wires.

Experiment. Measure the battery voltage by using a direct-current voltmeter with a 0- to 5-volt scale (see Fig. 36).

Step 1. Attach the test-point wires to the meter. Touch the test points to the battery terminals at *A* and *B*.

The meter will read the difference in voltage between the two terminals of the battery. (It should be $1\frac{1}{2}$ volts.)

Rule. Connect the voltmeter **across** *the part of the circuit in which the voltage is to be measured.*

Step 2. Now touch the test points to the tube base pins at *C* and *D*, to which the filament is attached. The meter measures a

difference of voltage across the filament. This voltage drop in the filament is caused by the loss of electrical energy that is changed to heat in the filament.

Step 3. Measure the difference in voltage across the filament of the second tube at *E* and *F*.

Why It Works. The circuit in Fig. 36 has three places to measure voltage: across the battery, at *A* and *B*, and across each of the filaments. Examine first the source of electrical energy, the battery. The chemicals in the battery, acting on the zinc, cause free electrons to collect on the negative side of the battery and to draw electrons from the positive side.

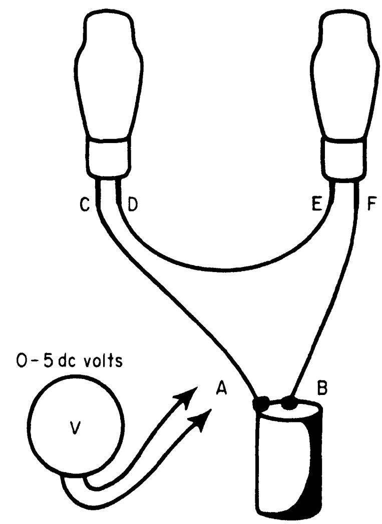


FIG. 36. Voltage measurements. Connect test points to a voltmeter and touch the points to the lettered parts of the circuit to measure the voltages between these places in the circuit.

The force exerted by the electrons at the negative battery terminal causes free electrons to flow through the wires to the filaments and back to the battery. The lack of electrons at the positive terminal pulls electrons from the circuit. Some voltage is lost in forcing the electrons through the resistance of the wires and the filaments. This loss of voltage is the voltage drop.

When you touch the test points to the battery terminals, the resistor in the voltmeter circuit allows only a weak current to flow through the meter coil. It shows there a voltage of $1\frac{1}{2}$ volts between the negative and positive terminals.

The fine tungsten-wire filament has a high resistance. The meter shows that there is a drop in voltage of about $1\frac{1}{2}$ volts across the filament. The electrical energy delivered by the battery is changed to heat in the tube filament.

How are higher voltages measured? You can use your 0- to 5-volt voltmeter to measure up to 50 volts by using a resistor having a higher resistance value. The resistance must be high

enough so that at 50 volts only enough current will flow through the coil to give full-scale deflection.

Questions

1. Draw a circuit diagram which shows how to make a milliammeter read either in volts or amperes.
2. Tell what is meant by voltage drop.
3. Why is it important to select a meter with such a range that the readings will usually come near the middle of the scale?

Technical Terms

ammeter—A meter used to measure the flow of current. Since the unit of electric current is the ampere, the meter is called an ammeter.

audio amplifier—A tube circuit used to amplify the audio-frequency output of the detector circuit.

bar magnet—A bar of steel that has been magnetized.

calibrate—To mark points on a meter scale in order that the pointer hand may correctly indicate the voltage, or units of current flowing. An ammeter is calibrated by connecting another previously calibrated ammeter to it, then adjusting the current so the pointer hand of the calibrated meter points in turn to each mark of its scale. The calibrating marks can then be made on the new meter.

D'Arsanval type of meter—A meter that has a permanent magnet and a moving coil.

dielectric—The insulating material placed between the plates of condensers.

direct-current meters—Voltmeters or milliammeters that measure direct voltage or direct current.

electromagnet—A coil of wire that acts as a magnet when a current flows through it. The coil is called an electromagnet to distinguish it from a permanent bar or horseshoe magnet.

galvanometer—A sensitive instrument that indicates a flow of current.

left-hand rule—A handy method of quickly finding either the direction of electron flow or the direction of the lines of force around a wire carrying a current.

lines of force—Hypothetical lines of magnetism used in studying and explaining the magnetic field.

magnetic field—The space in which the magnetic effect can be noticed.

magnetic poles—The ends of a bar or horseshoe magnet. A pattern of iron filings shows that the magnetism is strongest at these points. One pole is called north (N) or north-seeking and one south (S) or south-seeking, because when the magnet is hung by a string or a thread, one pole turns toward the north and the other toward the south.

magnetism—A force set up around a wire carrying a current. Also the force that exists at the poles, or ends, of a magnetized piece of iron.

milliammeter—A current-measuring meter calibrated to read and measure milliamperes.

milliampere—A unit of measurement, $\frac{1}{1000}$ ampere. Currents in the radio circuits you will study are measured in milliamperes (abbreviated ma).

permanent magnet—A magnet often made of hardened steel which holds its magnetism for long periods.

pivot bearing—A glass or jewel bearing for the metal pins that support the coil in a meter.

poles—The ends of a magnet.

resistance—The opposition of a wire or a conductor to the flow of an electron surge.

resistor—A short, compressed carbon rod or high-resistance wire wound on an insulating tube, used to limit or control the amount of current that flows in the circuit in which it is connected.

series—Batteries so arranged that the positive pole of one cell is connected to the negative pole of the next.

series connection—A circuit in which the electricity follows a single path.

shunt—Batteries so arranged that all positive poles are connected together and all negative poles are connected together. A shunt is also a wire or bar connected across an ammeter or a milliammeter so that the meter will measure higher currents.

shunt connection, or parallel circuit—A circuit in which the electricity follows two or more paths.

solenoid—A hollow coil of wire which forms an electromagnet. A soft iron plunger moves inside the coil.

step-down transformer—A transformer used to reduce, or step down, the voltage of a source of current. Bell transformers and toy-train transformers are used for reducing the voltage of house lighting circuits from 1 to 50 volts.

temporary magnet—A magnet, made with a soft iron core, that retains little or no magnetism. A coil is a temporary magnet because it is magnetic only while current is flowing through it.

terminals—Devices attached to the ends of wires or cables or to sets for convenience in making wiring connections. Battery terminals are also called *binding posts*. Spring clips are sometimes used as terminals on set boards.

triode tube—A tube with three elements: a filament or a cathode, a grid, and a plate.

volt—The unit of electrical pressure, or potential difference.

voltage drop—The loss in voltage, or the voltage used in forcing a current of electrons through a resistance.

voltmeter—An instrument used to measure the pressure exerted on the electrons in a circuit.

watt—The unit of power. Watts of power are found by multiplying the amperes of current by the voltage.

CHAPTER 5

OHM'S LAW BY SIMPLE MATHEMATICS AND BY METERS

Experiments are excellent to prove electrical laws and to show the way electricity acts in radio circuits. In this chapter you will perform experiments to learn how electricity acts in the simpler

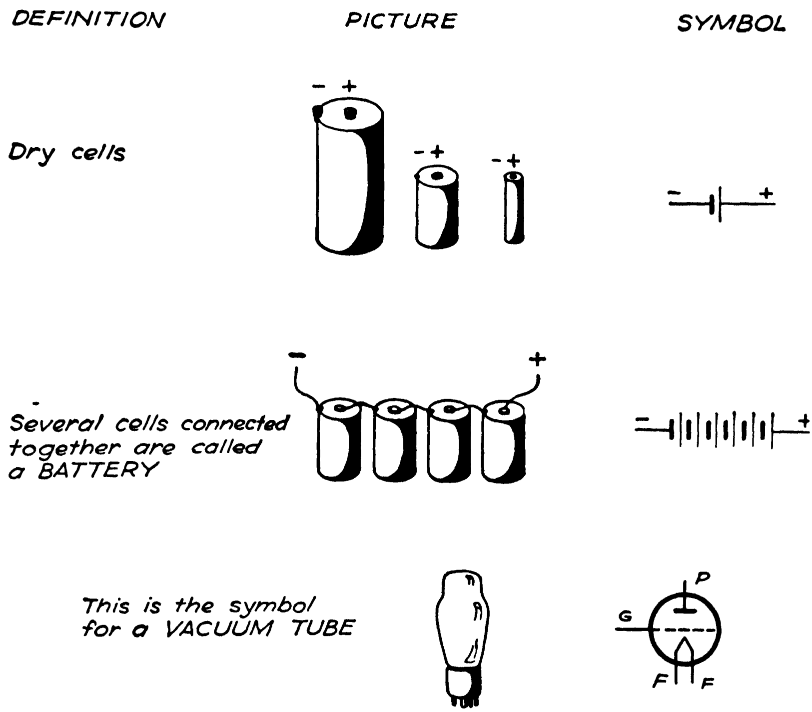


FIG. 37. New symbols used in this chapter. Note how they are used in the diagrams shown in the illustrations.

electrical and radio circuits found in radio sets. You will use meters to check the current and voltage in these circuits to prove the electrical laws that will be explained to you.

You will learn the following things in this chapter:

The new symbols that you will use in the figures in this chapter are for dry cells, battery of cells, and vacuum tube (see Fig. 37).

PART 1: WHAT THE NATURE OF VOLTAGE IS

How can we get different voltages? When you set up the first experiment in this chapter, you will find that you need different voltages. A handy way to get the voltage you need is to use ordinary No. 6 dry cells. The dry cells shown in Fig. 38 all have a voltage of $1\frac{1}{2}$ volts per cell.

What are a cell and a battery? Each separate unit in a battery is called a *cell.* When you connect several cells together, the group of cells is called a *battery.*

The size of the cell determines how long it can continue to supply a given amount of current. Large cells will last longer than small cells.

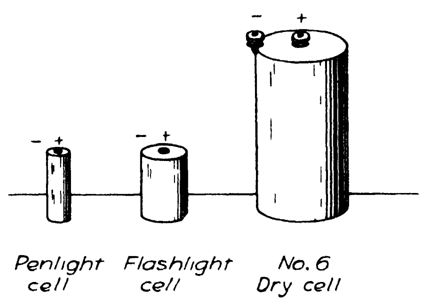


FIG. 38. Dry cells. The pen-light cell, the flashlight cell, and the No. 6 dry cell all have $1\frac{1}{2}$ volts electrical pressure. But the small cell has less current capacity than the large one.

What is the voltage of a series connection? Each cell of a three-cell automobile type of storage battery has 2 volts across its terminals when the cell is fully charged. The three cells will deliver 6 volts when the negative terminal of one cell is attached to the positive terminal of the next. The *current* of cells connected in series is the same as that delivered by only one cell. This is called a *series connection.*

Rule. When cells are connected in series, the resulting voltage is the sum of the voltages of all the individual cells. If a tube needs $22\frac{1}{2}$ volts supplied to its plate, 15 flashlight cells, connected in series, as shown in Fig. 39, will produce the desired voltage ($15 \times 1\frac{1}{2}$ volts $= 22\frac{1}{2}$ volts). The ordinary 45-volt B battery is

made by connecting 30 small dry cells in series and molding them into a block.

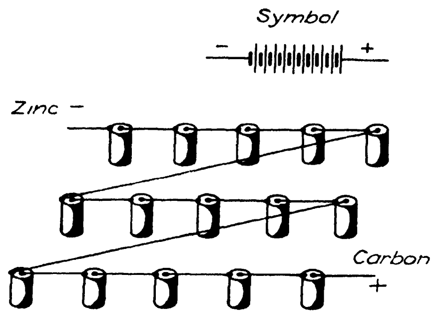


FIG. 39. Cells connected in series produce higher voltage than single cells. Here the voltages of all the cells add to a total of $22\frac{1}{2}$ volts. Note the positive and negative terminals.

What is the voltage of a parallel connection? *Rule. When cells are connected in parallel, the voltage remains the same as for one cell.* However, the current now is equal to the sum of the current from all cells. Dry cells used to heat a tube filament that requires $1\frac{1}{2}$ volts will have longer operating life if the cells are connected in parallel (see Fig. 40).

How are cells connected in series parallel? You can heat the filament of a 6-volt tube with dry cells by connecting them in

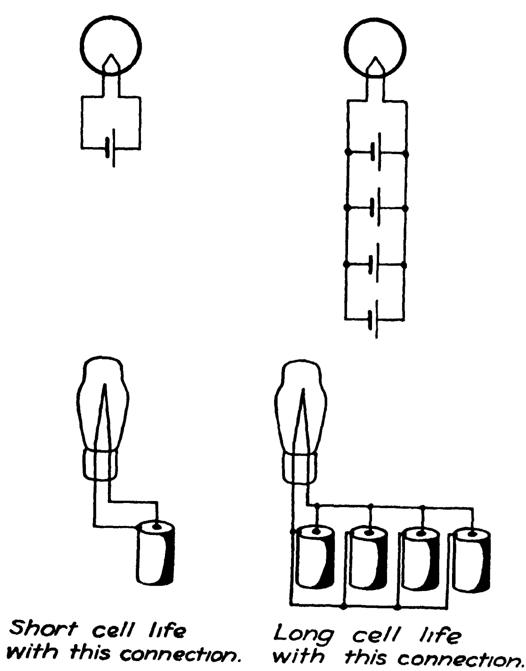


FIG. 40. A battery of cells connected in parallel. Four cells connected in parallel have the same voltage as a single cell, $1\frac{1}{2}$ volts; but they have much longer life than has the single cell.

series parallel, as in Fig. 41. Four $1\frac{1}{2}$-volt dry cells connected in series will have the 6 volts needed to operate a 6-volt tube. But the lives of the cells will be short if the filament uses much current. By connecting two more sets of four cells in series and then connecting the three sets of four cells in parallel, we increase the life of each cell by dividing up the current load among them all.

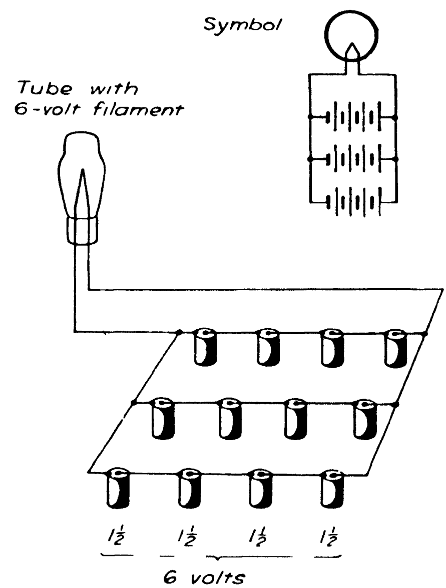


FIG. 41. Cells connected in series parallel. The four cells connected in series gives 6 volts. But when you connect the three sets of series-connected cells in parallel, you increase the life of the battery of cells.

PART 2: HOW OHM'S LAW RELATES CURRENT FLOW AND VOLTAGE

What is Ohm's law? There is a definite relationship between resistance, current, and voltage in an electrical circuit. This relationship was first stated by the German scientist, Ohm, in the year 1827. He observed that whenever he attached a battery with a definite voltage to a given resistor, the same amount of current would always flow through the connecting wire. He further observed that if he doubled the voltage, twice the amount of current would flow through the wire, or if he cut the voltage in half, only half the current would flow. From these facts he worked out what we now know as *Ohm's law*.

Ohm's law is written as $I = \frac{E}{R}$. This means that current (I) equals voltage (E) divided by resistance (R).

You can try this rule yourself by observing the brightness of a dial light as you change the voltage applied to it. Attach a $1\frac{1}{2}$-volt dry cell to a $6\frac{3}{10}$-volt dial light. Attach a 0 to 1 direct-current ammeter in the circuit, as shown in Fig. 42. Note the brilliance of the lamp and the reading of the meter. Then add a second dry cell in series so that there are 3 volts across the lamp.

Continue, adding a cell at a time, until you have 6 volts across the lamp, and make the same observations each time.

Write in a table, similar to the one shown in Fig. 43, the amount of current flowing through the lamp at each different voltage, and make a note describing the brilliance of the filament. This is an easy way to see, as Ohm did, that *more current will flow when the voltage is increased.*

You can see from the table that a higher voltage forced more current through the lamp filament and that the glow of the lamp is more brilliant when the current through it increases.

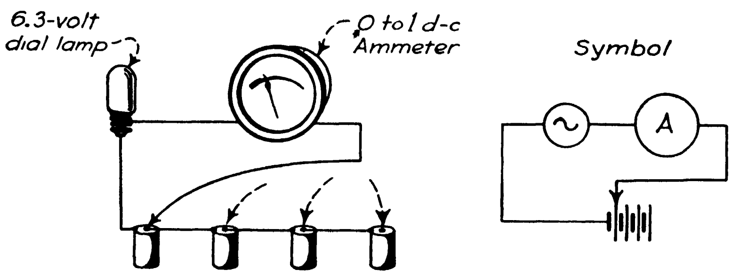


Fig. 42. Increase the voltage and current also increases. When you increase the voltage applied to the dial by moving the test point to the second cell, you will find that more current flows through the lamp. Still more current flows when you touch the test point to the third cell.

What dial or panel lamps are to be used? Select for the above experiment a 6- to 8-volt dial lamp which draws low current. The current used by dial lamps varies considerably. One type of lamp uses 0.25 ampere while another type of lamp uses 0.50 ampere.

For the next experiment select a 6- to 8-volt lamp that draws about twice the current. An example will make this clear:

Use a 6- to 8-volt lamp which draws 0.20 ampere for the first experiment.

Use a 6- to 8-volt lamp which draws 0.40 ampere for the second experiment.

What is the effect on current flow of increasing resistance? If a different dial lamp with a higher resistance filament is used, less current will flow through it. Prove this by performing the previous experiment, using a higher resistance lamp.

Again take readings on the meter, and watch the brilliance of the lamp as the battery voltage is changed. Write the meter readings in another table, similar to the one in Fig. 43.

Your observations show clearly that when you increase the voltage across the filament, more current flows. When you add a second cell so that the voltage across the filament is doubled, you find, as in the previous experiment, that the current is about twice as great as before. When you add a third cell, so that the voltage is nearly tripled, the current becomes almost three times as great.

Volts on lamp	Current seen on meter	Brilliance of lamp
$1\frac{1}{2}$		
3		
$4\frac{1}{2}$		
6		

FIG. 43. Copy this table and keep a record of the current flowing through the lamp. Also note the brilliance of the lamp.

You also find that the same voltage forces *less* current through a high-resistance lamp than through a low-resistance one. This means that *the same voltage will force less current through a higher resistance than a lower one.*

What facts have you just learned? Let us collect these facts so that you can understand better the results of these different conditions on the flow of the current.

Rule 1. (a) More current flows in a circuit when the voltage is increased, and (b) less current flows when the voltage is decreased, if the resistance remains unchanged.

Rule 2. Less current flows in a circuit when the resistance is made higher, if the voltage is unchanged.

How is Ohm's law mathematically expressed? The formula commonly used to show how much these changes of current, voltage, and resistance affect each other is known as Ohm's law. It is given below.

$$I = \frac{E}{R}$$

or

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}}$$

where I means current in amperes
E means voltage in volts
R means resistance in ohms

There are several interesting facts about this formula. The "equals" sign means that both sides of the formula are in bal-

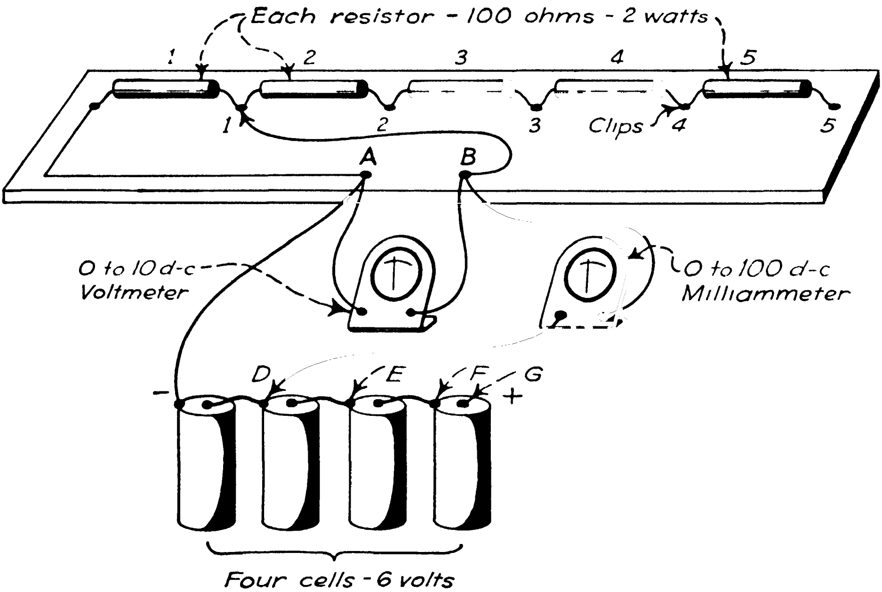


FIG. 44. Use resistors in series to prove Ohm's law. The milliammeter measures the current flow *through* the resistors in the circuit and the voltmeter measures the *voltage across* them. You can check the current flow through the resistors by the Ohm's law formula.

ance. When one side is made larger, the other side must also be made larger if they are to remain in balance. So, if the voltage is increased and the resistance is kept the same, more current flows. If the voltage is reduced and the resistance remains unchanged, the current must also drop. You can see this happen in a simple circuit.

Current and Voltage Increase Experiment

Wire the circuit by connecting two meters to the circuit board, as shown in Fig. 44. Connect a 0 to 10 direct-current voltmeter

across the A and B terminals and a 0 to 100 direct-current milliammeter in one wire, but do not attach the battery until later. Attach five 100-ohm 2-watt resistors to the clips on the experiment board.

How to Operate the Experiment

Step 1. Connect the wire from B to clip 1, so that one resistor is in the circuit. Read both meters with *no cell* of the battery connected.

Step 2. Attach the wires to *one* dry cell. Read the two meters. Make a table and write in it the observed values of current and voltage.

Step 3. Move the wire at D to add another dry cell in series and again read the meters. Write the current and voltage values in the table.

Step 4. Continue until all four cells are in the circuit. Write the current and voltage values in the table.

Why It Works

Ohm's law tells you that the amount of current that flows through a resistor will increase as you increase the voltage across it. When the first cell is connected, the voltmeter shows $1\frac{1}{2}$ volts. You know from the manufacturer's specifications that one resistor has a resistance of 100 ohms.

Problem. Now use the formula to find how much current should flow through the resistor.

Step 1. Write down the formula

$$I = \frac{E}{R}$$

Step 2. Write down here the numbers you have to work with

$$\begin{aligned} I &= \text{what you want to find} \\ E &= 1\tfrac{1}{2} \text{ volts} \\ R &= 100 \text{ ohms} \end{aligned}$$

Step 3. Substitute the numbers in the formula, and write numerator and denominator as fractions

$$I = \frac{1\frac{1}{2}}{100} \text{ or } \frac{\frac{3}{2}}{\frac{100}{1}}$$

Step 4. Invert the denominator and multiply (3×1 and 2×100)

$$I = \tfrac{3}{2} \times \tfrac{1}{100}$$
$$= \tfrac{3}{200}$$

Step 5. Divide numerator by denominator to find the answer

$$I = 0.015 \text{ ampere}$$

Step 6. Multiply by 1000 to get the answer in milliamperes.

$$I = 15 \text{ milliamperes}$$

This is the answer. Check this on the milliammeter, which should give you approximately the same answer.

If you find that the milliammeter reading is different from the current value you worked out by Ohm's law, the reason probably is that the actual resistance of these resistors was not exactly 100 ohms. Commercial resistors vary as much as 20 per cent from the value marked on them.

You can also purchase resistors marked with either a silver or a gold band. The silver band means that the resistor is within 10 per cent of its rated value. A gold band means the resistor is within 5 per cent of its rated value. Or you can purchase precision resistors which will give much more accurate results in this experiment.

When you add a second dry cell in series with the first, you find that there is twice the voltage across the resistor and that about twice as much current flows through it.

Two dry cells connected in series deliver a voltage of 3 volts. Check this on the voltmeter. Now, before you check the reading of the milliammeter, work out by Ohm's law the amount of current that should flow at the new voltage.

$$I = \frac{E}{R}$$

where I = what you want to find
E = 3 volts across the resistor
R = 100 ohms

$$I = \frac{3 \text{ volts}}{100 \text{ ohms}}$$
$$= 0.03 \text{ ampere}$$
$$= 30 \text{ milliamperes}$$

The meter reading should agree approximately with your mathematical result.

Using the formula, work out the amount of current that will flow when you attach three, and then four, dry cells in series. Check your figures against the readings of the two meters. In this way you can see that the higher voltage forces a greater current flow through the resistors.

The Current Decrease and Resistance Increase Experiment

You can connect a larger resistor in the circuit to show the effect that a change in the resistance of a circuit has on the amount of current flowing through it.

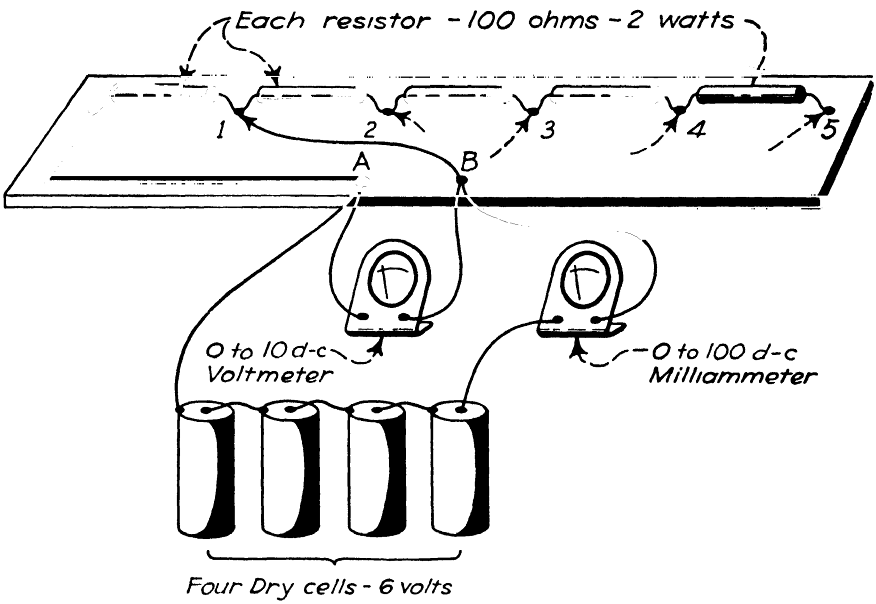


FIG. 45. The current flow decreases as the resistance becomes greater. The voltage remains the same in this experiment.

How to Wire the Circuit

Connect a 100-ohm resistor in the circuit as shown in Fig. 45. Connect four dry cells in series to get 6 volts, or use a 6-volt storage battery. Connect a 0 to 100 direct-current milliammeter in series as shown.

How to Operate the Experiment

Step 1. Read the milliammeter to find out the amount of current flowing through the 100-ohm resistor. Make a table, and write the amount of the current flow in it (see Fig. 46).

Number of resistors	CURRENT FLOW	
	By Ohm's Law	By Milliammeter
5		
4		
3		
2		
1		

FIG. 46. Copy this table. Write in it the results of your test.

Step 2. Move the wire from clip 1 to clip 2. You now have 200 ohms in the circuit. Measure the current that flows through the 100-ohm resistors. Write the figures in the table.

Step 3. Continue, moving the wire next to clip 3, then to clip 4 and to clip 5. Write data in the table for each new value of resistance.

Why It Works

The 6 volts of the battery can force more current through a 100-ohm resistor than it can force through two 100-ohm resistors in series (200 ohms). There is now more resistance in the circuit, and so less current flows. You can prove this by Ohm's law.

How to Plan the Problem

Problem. Find the current through the 100-ohm resistor.

$$I = \frac{E \text{ (of battery)}}{R \text{ (of resistor)}} = \frac{6 \text{ volts}}{100 \text{ ohms}} = 60 \text{ milliamperes or } 0.06 \text{ ampere}$$

When 200 ohms is in the circuit, the current is found as follows

$$I = \frac{E}{R}$$

where I = the current to be found
E = 6 volts
R = 200 ohms

$$\begin{aligned} I &= \tfrac{6}{200} \\ &= 0.03 \text{ ampere} \\ &= 30 \text{ milliamperes} \end{aligned}$$

and for 500 ohms the solution is as follows

$$I = \frac{E}{R}$$

where E = 6 volts
R = 500 ohms

$$I =$$
$$= 0.012 \text{ ampere}$$
$$= 12 \text{ milliamperes}$$

These figures show how the current flow decreases when you increase the resistance in a circuit.

Question

Look in radio-tube characteristics charts in radio handbooks and in catalogues for the voltage and current required for several dial lights. From this data calculate the hot resistance of the filaments.

PART 3: HOW SERIES CONNECTIONS AFFECT RESISTANCE

Resistors are often connected in series. There are many places in the radio circuit where resistors, tube filaments, transformers, and other parts must be connected in series. You will study one such circuit in Chapter 14, "Power Supplies." It is important that you know just what the effect will be when several resistors are connected in series.

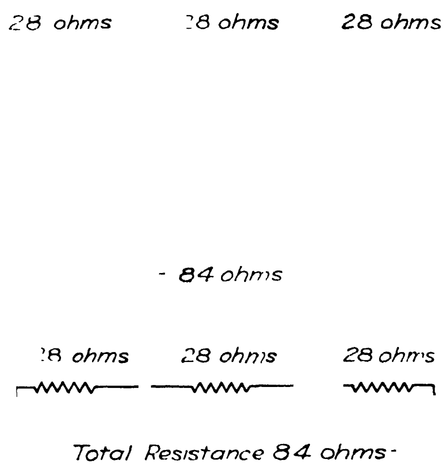


FIG. 47. When connected in series, resistances add.

When connected in series, the resistances add. *Rule: When two or more resistors are connected in series, their total resistance is equal to the sum of each resistance.*

The three 1LE3 tubes (shown in Fig. 47), each with a 28-ohm filament at full voltage, have a total resistance of 84 ohms when connected in series.

$$
\begin{aligned}
R_{\text{in series}} &= R_1 + R_2 + R_3 \\
&= 28 \text{ ohms} + 28 \text{ ohms} + 28 \text{ ohms} \\
&= 84 \text{ ohms}
\end{aligned}
$$

The same principle applies when tubes of different types are connected in series (see Fig. 48).

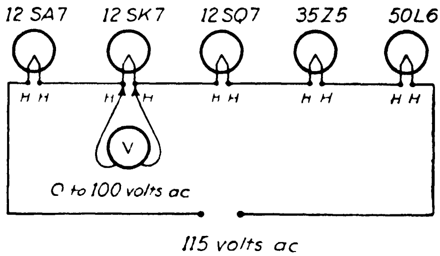


FIG. 48. Here the heater filaments of a five-tube set are connected in series. Some of the tubes have different hot resistances so the voltage drop, measured by the meter across each filament, is different.

Problem. Suppose a set has these tubes: a 12SA7, a 12SK7, a 12SQ7, a 35Z5, and a 50L6. Find the resistance of these filaments when hot by this formula

$$R_{\text{total}} = R_1 + R_2 + R_3 + R_4 + R_5$$

where R_1, the 12SA7 = 84 ohms
R_2, the 12SK7 = 84 ohms
R_3, the 12SQ7 = 84 ohms
R_4, the 35Z5 = 233 ohms
R_5, the 50L6 = 333 ohms

$$
\begin{aligned}
R_{\text{total}} &= 84 + 84 + 84 + 233 + 333 \\
&= 818 \text{ ohms}
\end{aligned}
$$

PART 4: HOW PARALLEL CONNECTIONS AFFECT RESISTANCE

How is the total resistance affected when resistors are connected in parallel? When resistors are connected in parallel, the resistance of the group drops. The total resistance is less than the resistance of any one of the resistors.

Here is the formula used for resistors connected in parallel

$$R_{\text{total}} = \frac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2}}$$

Problem. What will be the total resistance of two 6C5 heater filaments when connected in parallel? Each heater filament has a resistance of 21 ohms. (Find this in the Selected Tube List, pages 668 669. The 6C5 heater uses 6.3 volts and 0.3 ampere of current. R_1 by Ohm's law then is 21 ohms.)

Step 1. Write the formula and the value of R_1 and R_2.

$$R_{\text{total}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$

where $R_1 = 21$ ohms
$R_2 = 21$ ohms

Step 2. Write the values in the formula and add the numerators of the lower fraction

$$R_{\text{total}} = \frac{1}{\frac{1}{21} + \frac{1}{21}} = \frac{1}{\frac{2}{21}}$$

Step 3. Invert the lower fraction and multiply. Then divide the numerator by the denominator to find the answer.

$R_{\text{total}} = \frac{1}{1} \times \frac{21}{2} = 10.5$ ohms, total resistance for the two heaters connected in parallel.

Rule. When two resistors with the same resistance are connected in parallel, the total resistance is half the resistance of either one.

How is the resistance of several resistors connected in parallel found? What happens to the combined resistance when several resistors, each with a different resistance value, are connected in parallel?

Problem. What is the total resistance of the filament circuit in a set using these tubes: a 6SJ7, a 6L6, and a 6F6. The formula given above may be used.

This example is worked out as follows:

Step 1. Write the values, then substitute them in the formula.

Where R_1, the 6SJ7 = 21 ohms
R_2, the 6L6 = 7 ohms
R_3, the 6F6 = 9 ohms

$$R_{\text{total}} = \frac{1}{\frac{1}{21} + \frac{1}{7} + \frac{1}{9}}$$

Step 2. Find the common denominator, so that you can add the fractions. Try 63 for the denominator (21, 7, and 9 will divide evenly into it).

$$R_{\text{total}} = \frac{1}{\frac{3}{63} + \frac{9}{63} + \frac{7}{63}} = \frac{1}{\frac{19}{63}}$$

Step 3. Now clear of fractions by inverting the lower fraction; then divide to get the answer.

$$R_{\text{total}} = \frac{1}{1} \times \frac{63}{19} = \frac{63}{19} = 3.3 \text{ ohms, total resistance}$$

There is a voltage drop across a resistor. Now that you have seen how the resistances of series and parallel circuits are computed, you are ready to discuss again the important factor called *voltage drop*. Examine the circuit in which five tubes are connected in series (see Fig. 48). A voltage drop occurs because the voltage of the line is used up in forcing the electron flow to continue through the resistance of the five heater filaments. Part of the voltage is used to force the current to flow through the first filament. The difference of voltage between the two ends of the filament can be measured by a voltmeter. It is the voltage drop across the filament.

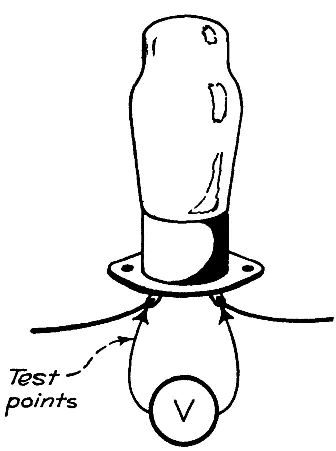


FIG. 49. When the voltmeter is connected *across* the tube-filament terminals, 1 and 8, it measures the difference of voltage or the voltage drop across the filament.

Experiment. Attach test points to a 0 to 10 direct-current voltmeter (see Fig. 49). Touch the free ends of the test points across the Nos. 1 and 8 pins of the first tube. The reading of the meter is the voltage drop across the filament of that tube.

Check this reading by Ohm's law. You know the resistance of the filament and the amount of current flowing through the circuit. Remember that the amount of current flowing is the same in all parts of a series circuit. Use the formula $E = I \times R$ to find the voltage drop E across the tube.

When resistors are connected in parallel, a new condition occurs:

There are two possible paths for the electron flow to follow on its way through the circuit. When both resistors have the same resistance, the current will divide equally, and half will flow through each resistor.

Experiment

Step 1. Connect the filaments of two 1LE3 vacuum tubes as shown in Fig. 50.

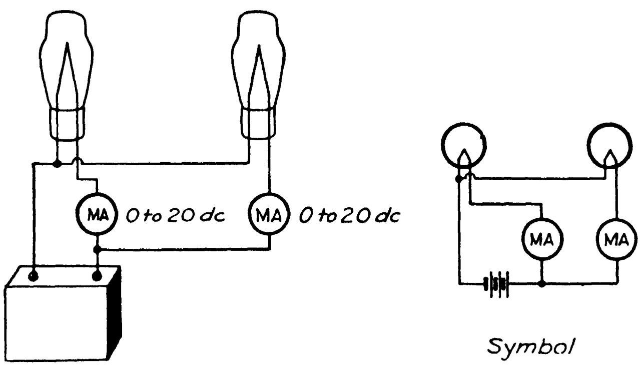


FIG. 50. When resistors are connected in parallel the total resistance in the circuit is less than the resistance of either of the single resistances. You can see the effect of a parallel connection in this circuit by noting the current flow as shown by the two meters.

Step 2. Connect two 15-milliampere dial lamps in parallel. You will note from the glow of the lamps that an equal amount of current flows through each branch of the circuit. Prove this by connecting a 0 to 20 direct-current milliammeter in each branch of the light circuit.

Rule. When two resistors of equal size are connected in parallel, the total resistance is half the resistance of either one of the resistors.

But when two resistors unequal in size are connected in parallel, the total resistance is less than the resistance of the smaller of the two. The formula is

$$R_{\text{total}} = \frac{R_1 \times R_2}{R_1 + R_2}$$

Example. Suppose that two resistors of 500 ohms and of 200 ohms are connected in parallel. What will be their total resistance?

$$R_{total} = \frac{500 \times 200}{500 + 200}$$
$$= \frac{100{,}000}{700}$$
$$= \frac{1000}{7}$$
$$= 142.85 \text{ ohms}$$

Other combinations of resistors occur in radio circuits but will be left for more advanced study, since they involve more difficult

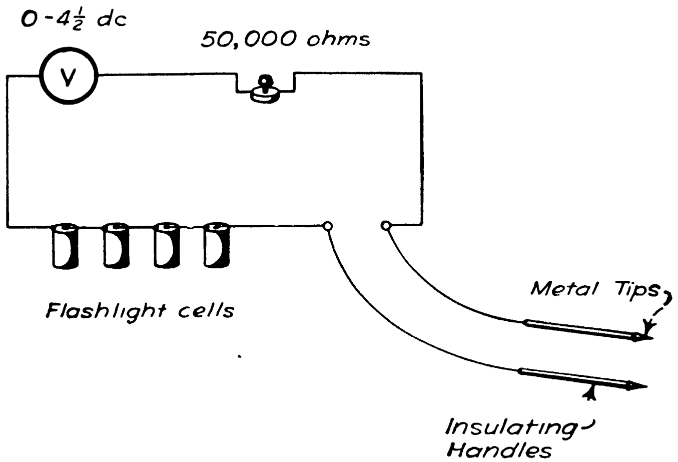


FIG. 51. Connect a meter and the parts shown here and you have an ohmmeter.

mathematical computations beyond the scope of your present work.

Questions

1. What will be the total resistance of two 1LE3 tubes connected in parallel?

2. What will be the total resistance when the following three tubes are connected in parallel: 1A7, 3Q5, and 1LE6?

3. Many portable sets have all of the tubes connected in series, including the power tube. What will be the total resistance when the following tubes are used: 1H5, 1N7, 1LA6, and 117Z6?

PART 5: A PRACTICAL WAY TO MEASURE RESISTANCE—THE OHMMETER

The voltmeter-ammeter method is only one way to measure resistance. There are several ways to measure resistance. If you want to find the resistance of a tube filament, you could measure the voltage across the filament (see Fig. 49), measure the

current flowing in the circuit, and then use Ohm's law to find the resistance.

This is an accurate method and one which is used in laboratory testing. But for practical work on the radio test bench and for work by most experimenters, the ohmmeter is a much handier and more useful way to measure resistance.

What is an ohmmeter? The ohmmeter is merely a low-range voltmeter connected in series with a battery and a variable resistor.

An inexpensive ohmmeter may be made of a 0 to $4\frac{1}{2}$ direct-current voltmeter, a 6-volt battery, and a 50,000-ohm variable resistor. It is wired as shown in Fig. 51.

Experiment in Operating the Ohmmeter

Step 1. Connect one test-point wire to the battery and one to the rheostat, as shown in Fig. 52.

Step 2. Touch the test points together. The meter now reads the voltage of the meter battery, less the drop in voltage across the rheostat. Adjust the meter hand to 0 ohms ($4\frac{1}{2}$ volts) by turning the rheostat.

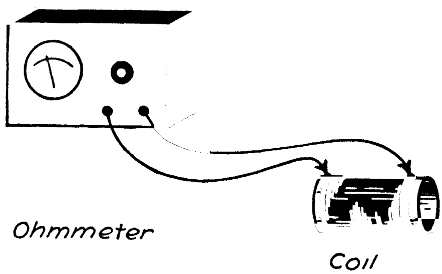


FIG. 52. You can use the ohmmeter to test a coil to find if the wires are broken. This is called a *continuity test.*

Step 3. Touch the test points to the part of the circuit where you want to measure resistance, such as across the F pins of the tube on a circuit board. The meter will read the *cold* resistance of the filament.

Continuity Tests with the Ohmmeter

You can read directly the resistance of resistors and the resistance of coils with the ohmmeter and make many circuit tests with it. Servicemen use the ohmmeter to locate trouble in radio circuits. For instance, a loose or broken wire or a poorly soldered connection, common sources of trouble, can easily be located with the ohmmeter.

Connect test points to an ohmmeter, and touch the free ends of the test points to the ends of a coil (see Fig. 52). If the coil is

good, with no poor connections or broken wires, its resistance will be very low. A poor joint will show as a high resistance reading. A broken wire will break the circuit, and, consequently, the meter hand will not move but will indicate infinite resistance. This is called an *open circuit* or an *open.*

Why It Works

Examine the circuit of the ohmmeter shown in Fig. 51. It consists of a voltmeter connected in series with a battery and a variable resistor. When you touch the test points together, you really are measuring the voltage of the battery.

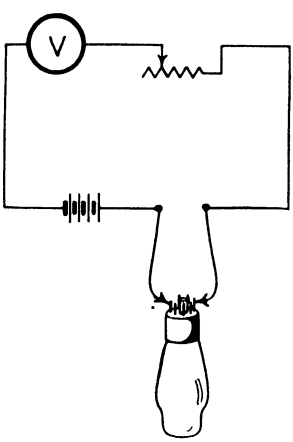


FIG. 53. Touch the test points of the ohmmeter to the 1 and 8 pins of a tube to test for a burned-out filament.

This battery voltage is higher than the highest mark on the meter scale, in order to allow for aging of the battery. When you touch the test points together, the meter hand can be set back to zero by means of the variable resistor. When you make this adjustment, you automatically compensate for the resistance of the test-point wires.

Now, when you touch the test points to the filament terminals of a tube or of any other resistor, the resistance of the filament is in series with the battery and meter (see Fig. 53). The added resistance cuts down the current flow in the circuit and the meter reads a lower voltage.

The ohmmeter scale is marked in ohms. When you set the test points across a high resistance, the ohmmeter shows a high-resistance reading (a low voltage); when you set the test points across a low resistance, the ohmmeter shows a low-resistance reading (a high voltage).

Questions

1. How many ways can you find for measuring resistance?
2. Make a cutaway drawing of an ohmmeter.
3. What is the purpose of the variable resistor in an ohmmeter?
4. Can you design a circuit for an ohmmeter which uses an ammeter instead of a voltmeter?

Technical Terms

battery—A group of electric cells connected together.

cell—Each unit of a storage battery. You use one or more dry cells in your flashlight.

continuity test—A test, often made with an ohmmeter, to find whether there is a break in the circuit.

dry cell—A chemical device for producing a current of electricity. It consists of a zinc can containing a moist paste of ammonium chloride, manganese dioxide, and graphite, with a carbon rod in the center.

∞—The mathematical symbol for infinity.

Ohm's law—Current = volts/ohms (written as $I = E/R$). This formula shows that if you double the volts without changing the resistance, you will double the current; but if you double the resistance without changing the voltage, you will cut the current in half.

open—A word used to mean that there is a break in the circuit.

parallel connection—Whenever the ends of two or more conductors are connected to the same terminals, or whenever like terminals of cells are connected together (see Fig. 40), they are said to be connected in parallel.

CHAPTER 6

HOW TO BUILD AND WIRE THE TUBE CIRCUIT BOARD

Whether you work at home, in the garage or basement, or in the classroom, you will get a great deal of valuable radio training and experience from building set boards. While these boards are designed specifically for purposes of study, they are surprisingly effective as receivers and transmitters.

When this book is to be used as a classroom text, it is suggested that each circuit described in it be built on standard baseboards for convenience in setting up different circuit combinations and for storage. The construction of typical circuit boards is described in this chapter.

You will learn the following things in this chapter:

Part 1: How the Tube Circuit Board Is Built
Part 2: How the Parts Are Fastened to the Baseboard
Part 3: How the Circuit Is Wired
Part 4: How the Soldering Iron Is Tinned
Part 5: What Soldering Fluxes Should Be Used
Part 6: How a Wire Joint or a Wire Splice Is Soldered
Part 7: How Wires Are Spliced

PART 1: HOW THE TUBE CIRCUIT BOARD IS BUILT

The circuit board shown in Fig. 54 is used not only for the experiments that demonstrate the theory of the vacuum tube but also for other experiments in your study of radio circuits. You will use it as part of a simple receiving circuit.

On this tube circuit board is mounted the tube socket into which the tube is plugged, the wiring for each of the three tube circuits, the filament heater, the grid, the plate, and the necessary binding posts to which wires from the other parts of the circuit are connected. You will find it handy to have several one-tube circuit

boards for use later in experiments. The other circuit boards will have the same wiring.

There are three separate circuits on this board: the *filament circuit*, the *plate circuit*, and the *grid circuit*. Study the filament and the plate circuit first. You will study the grid circuit later.

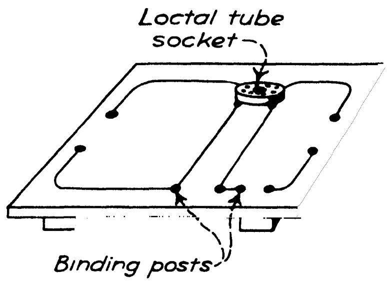


FIG. 54. This is the tube circuit board that you will use for many experiments designed to help you to learn about the action and theory of the vacuum tube.

The filament circuit includes the tube filament, the wiring, and the dry cell. We call the filament, the dry cell, and the wiring the filament circuit (see Fig. 55).

The plate circuit runs from the plate of the tube to the output posts, then to the B battery, and back to the filament (see Fig. 56).

What is a schematic circuit drawing? When you want to show a circuit, you draw a simplified sketch of the tubes, batteries, and wires. You draw standardized symbols to represent the tube, the batteries, and the wiring. Let us see how this tube circuit would look drawn as a schematic diagram. In Fig. 57 the whole circuit is represented by symbols. Note that each symbol looks like the thing for which it stands. You can easily recognize from their symbols the tube and the binding posts. The wiring is shown by connecting lines. Note the dot where wires are connected. Where wires cross, no dot is shown.

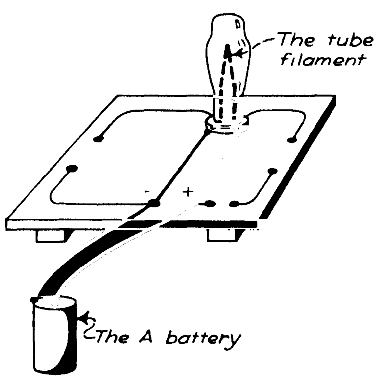


FIG. 55. The heavy lines show the *filament circuit* on the tube board.

The battery symbol uses a short, heavy line to represent the negative terminal and a long, light line for the positive.

What size should the baseboards be? Mount this simple tube circuit (and many others) on $9\frac{1}{2}$-in. × 10-in. × $\frac{5}{8}$-in. thick pine

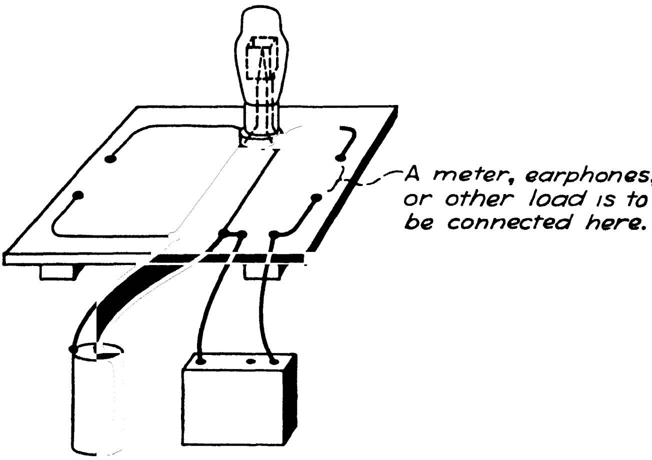


FIG. 56. The *plate circuit* is shown here in heavy lines.

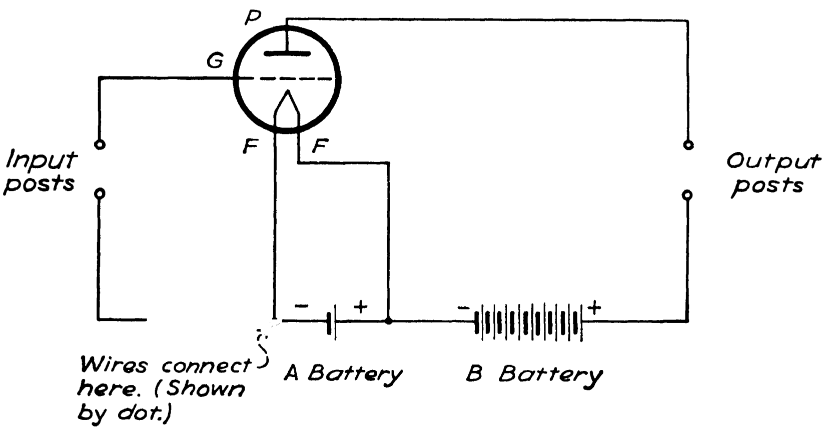


FIG. 57. This is a *schematic diagram*. It is a quick way to draw the circuit of the tube circuit board. Note that symbols are used in place of the more complicated drawings of each piece of apparatus.

or other suitable material. (Other circuits requiring more space can be mounted on boards 10 in. × $20\frac{1}{4}$ in. of the same material.) Nail or screw and glue two $\frac{3}{4}$-in. × $1\frac{1}{2}$-in. cleats to the undersurface of the boards to prevent it from warping and make it easy to pick up.

Lacquer or paint the board to keep it clean. Store it in a cabinet. Stamp or paste a number on the edge of the board and

on the cabinet to show the storage position of the set. Type or print a name plate to show the name of the circuit mounted on the board.

Where can you obtain the parts? Use new parts for these sets, or salvage parts from old broadcasting receivers. Most people are glad to give old sets to a school or to experimenters. Tube sockets that will mount flat on the board are rare. Wafer sockets are suitable and inexpensive and are easy to obtain. They can be mounted in several ways.

What are binding posts? Several kinds of binding posts can be used. The small- or medium-sized Fahnestock posts are excellent if straight wire is to be used for connection between boards. Fasten the posts to the board with $\frac{1}{2}$-in. × 6-in. roundhead blued or bright wood screws. Banana-plug and jack or phone-tip and jack connections are handy, but they are apt to wear out quickly.

If wires with attached alligator clips are used for the connectors, roundhead wood screws, or even finish nails, can be used for wire terminals.

PART 2: HOW THE PARTS ARE FASTENED TO THE BASEBOARD

The positions of parts on the baseboard are important because these sets are arranged so that the wiring looks like the drawing of the schematic circuit diagram. Set the parts and the binding posts on the board, and observe their positions carefully. Have all the wires on top of the board clearly in sight. Fasten the parts to the board with small roundhead wood screws.

Wire these sets with No. 14 bare, tinned, or enameled copper wire. The tinned copper wire is preferred. Make square corners so that the wire follows the schematic circuit. Staple the wires to the board.

PART 3: HOW THE CIRCUIT IS WIRED

How do you wire the filament circuit? The filament circuit includes the tube filament, the tube socket, the two binding posts, a dry cell, and the necessary connecting wire (see Figs. 55 and 58). Run a wire from the A-minus binding post to the A-minus terminal on the tube socket. Run a wire from the A-plus terminal of the tube socket to the A-plus binding post. Fasten the wires to the board with staples. This completes the filament circuit.

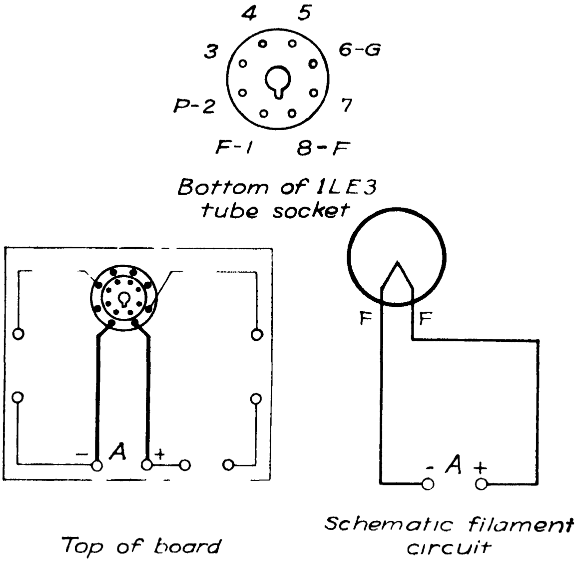


FIG. 58. This shows the position of the parts on the set board. The filament circuit is shown in heavy lines. Note that the parts are laid out in the same form as the schematic diagram. This is an important training aid.

Note the bottom views of the tube socket. The bottom view is shown this way in tube manuals because the bottom of the socket is the part the builder or repair man sees when he works on a set mounted in a metal chassis.

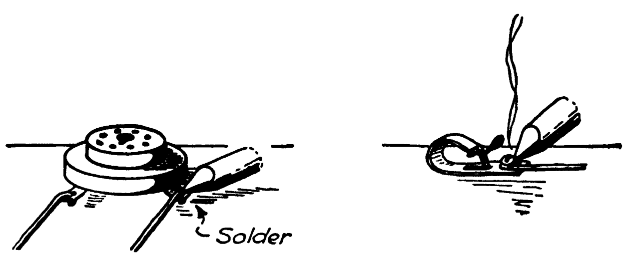


FIG. 59. Solder all connections. Loose joints soon become dirty and the resistance of the joint increases. This produces noise in the set, erratic operation, or sometimes completely stops the set.

Scrape the insulation off the end of the wire where you expect to solder it. Slip the wire through the hole on the tube-socket clip, bend over the wire end, and solder in place (see Fig. 59). All wires should be soldered to the binding posts and to the lugs on the tube socket. The method of soldering is explained in Part 4 of this chapter.

How do you attach the wires to binding posts? You can use clips as shown here or substitute posts. Scrape the end of the wire, bend it, and solder it to the screw or clip as shown in Fig. 59.

How do you wire the plate circuit? Run a wire from the plate post of tube socket to one output binding post (see Fig. 60). Run a wire from the second output binding post to the B-plus binding post. Run a third wire from the B-minus binding post to the A-plus binding post.

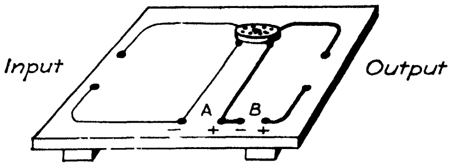


FIG. 60. Now wire the plate circuit. It is drawn in heavy lines.

The plate circuit runs from the plate to the output binding posts (see Fig. 61) with connections to the B battery and a wire from the B-minus terminal back to the filament, either through the rheostat or through the A battery.

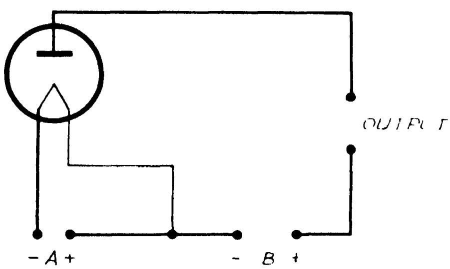


FIG. 61. Schematic diagram of the plate circuit.

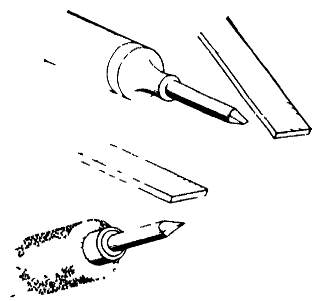


FIG. 62. How to file the tip of a soldering iron.

PART 4: HOW THE SOLDERING IRON IS TINNED

A soldering iron point, or tip, is made of copper, which conducts heat very well. The tip is filed as shown in Fig. 59 or as in Fig. 62, because the hot copper surface at the end of the iron oxidizes and hardens, and solder will not stick to it. To remove this oxide, it is customary to file the iron clean while it is hot and re-tin it. A thin coating of solder is melted onto the surface of the clean, hot copper so that it will readily hold and carry a drop of hot solder to the work. This process is called *tinning the iron*, and the procedure is as follows:

Step 1. Heat the iron to the proper soldering temperature. With an electric iron all that needs to be done is to turn it on, and it will reach the proper heat in about 2 minutes.

Step 2. File the tip until the bright copper shows over the entire surface. This should require just a few strokes of a clean file. The heated copper will rapidly discolor again, but this discoloration will be cleaned off by the flux, which is the substance to be applied to the surface for soldering.

Step 3. Either dip the hot tip of the soldering iron into some form of flux or touch rosin-core solder to the hot tip. The flux will clean off this oxide and permit the solder to flow onto the copper and cover it. If rosin-core solder is used, do not dip the iron in flux. The purpose of the flux is to combine with the impurities and clean them off.

When the hot iron has been left on its stand for 30 minutes or longer, it often will not solder a joint even though the iron is quite hot. This occurs because the iron has "burned." File off the hardened solder, and re-tin the point. The iron will now solder satisfactorily.

PART 5: WHAT SOLDERING FLUXES SHOULD BE USED

There are several kinds of soldering fluxes on the market, almost any of which may be used satisfactorily by the amateur for soldering on his set. Select a soldering flux that will not corrode the metal after the joint has been made. Any electrician can tell you a number of good commercial fluxes to use. The local radioman can also give you this information.

Many fluxes are fairly good conductors of electricity at high frequencies. Amateurs who have made a set carefully and well often wonder why the set does not operate better. Frequently the answer is that the soldering flux has flowed not only on the joint but over the Bakelite, or other insulation, in such a way as to furnish a path through which the high-frequency currents flow to parts of the circuit where they do not belong. This cuts down the efficiency of the set and may render it inoperative.

Many amateurs prefer to use rosin-core solder, since rosin is not a conductor of electricity. Rosin is a good flux for clean, new copper or brass. But the rosin sometimes flows into a joint and hardens between the turns of the wire. Such a joint will not

carry electricity, since the rosin prevents the two metals from making contact. Take such a joint apart, scrape it clean and bright, then resolder. Sometimes reheating with a hot iron will flow in the solder and will make a good joint.

PART 6: HOW A WIRE JOINT OR A WIRE SPLICE IS SOLDERED

Soldering may be done easily if three rules are followed:

Rule 1. The joint must first be cleaned. This means that all surfaces of the two pieces of metal that are to be joined together by the solder must be scraped clean or must be cleaned with some chemical. In radio work we scrape wires with a knife, being careful to see that *all* parts of the joint are clean and bright.

Rule 2. The soldering iron must be clean and well tinned. An iron that has been overheated or left on for a long time gradually burns. The hot solder combines with the oxygen in the air to form a hard oxide surface that will not conduct the heat from the iron to the joint to be soldered. If this has happened, the iron must be filed and re-tinned.

Rule 3. The iron and the joint must both be hot. If the iron feels quite hot when held near the face or hand, it should solder the joint nicely.

When the iron and the joint are sufficiently hot, apply the flux. Use very little flux on the joint. The flux melts and flows through the whole joint, cleaning the surface of the metal by chemical action.

Then apply the solder. When the joint and the iron are thoroughly hot and clean, the solder will flow into the joint quickly and make a smooth joint.

If the solder seems to be rough and follows the iron away from the joint and forms a sharp point, this is a sure indication that the iron or the joint, or both, are not hot enough.

Special solders and fluxes must be used when soldering aluminum.

PART 7: HOW WIRES ARE SPLICED

Step 1. Cut or scrape the insulation off the wire for about 3 inches. Scrape the wire till it is clean and bright. Slice off the insulation, moving the knife along the wire so as not to cut the wire. Copper breaks easily where it is scratched or marked with a knife or pliers. In making an antenna, this is very impor-

tant, since the antenna wire will break at such a cut and will fall after it has been in the air a short time. Make a light cut on a piece of scrap wire, and then bend the wire to see how a very small nick in the wire will make it break easily. Now try bending a wire that has not been nicked.

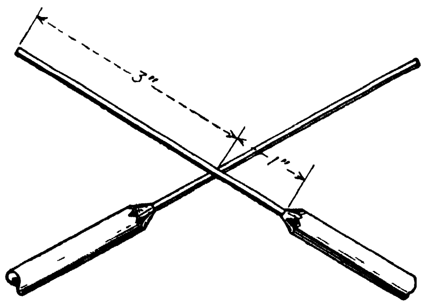


FIG. 63. These wires are ready to splice.

Step 2. Hold the wires together, as shown in Fig. 63.

Step 3. Twist one wire around the other for several turns; then start with the second wire, and twist it around the first. Keep the first few twists very tight. Make at least four twists with each wire, bending one wire almost at right angles to the other wire (see Fig. 64). Do not wrap the turns of the joint too

FIG. 64. This is the way to twist the wire splice. It is now ready for soldering.

closely together, as this will prevent the solder from flowing into and around all parts of the joint. This splice will be sufficiently strong to join parts of an antenna together where there is considerable strain.

Step 4. The wire, which was scraped clean before the joint was made, is now soldered. This solder helps make the joint more solid and also prevents any corrosion by the air or sun.

Questions

1. Why is the soldering iron made of copper instead of iron?
2. Why must a soldering iron be tinned?
3. What is the purpose of soldering fluxes?
4. Why is rosin preferred as a flux for radios?
5. What harm comes from letting a soldering iron get too hot?
6. Why are radio connections soldered? List several reasons.

Technical Terms

binding posts—Connectors to which wires from batteries or from other unit circuits may be attached.

burned iron—A soldering iron left connected too long burns and will no longer solder. The hot liquid solder on the tip oxidizes and hardens and no longer is a good heat conductor.

filament circuit—A circuit including the filament and the A battery, with their connecting wires.

grid circuit—A circuit including the grid, a tuning circuit, or a coupling circuit, the grid-return wire, and the filament.

plate circuit—A circuit including the filament, the plate, the earphones or other load, the B battery, and the connecting wires.

schematic diagram—A wiring diagram showing the coils, condensers, resistors, and other parts in simplified form.

soldering flux—A chemical compound which removes oxides from the wire or metal surface so that the hot solder will adhere to the surface.

soldering iron—An electric iron with an encased heating element, a copper tip to carry the heat to the work, a handle, and a connecting cord. (Soldering "iron" should be soldering "copper.")

tinning—Filing clean the copper tip of a soldering iron, and flowing melted solder on the clean tip.

tube sockets—Plastic or ceramic forms in which springs are molded or fastened. When the tube is placed in the socket, the tube pins pass through holes in the plastic and make contact with the proper circuit wires.

CHAPTER 7

PRINCIPLES OF THE VACUUM TUBE

Think of radio, and you think of the vacuum tube. The purpose of this chapter is to help you to learn something about the theory and operating principles of a simple vacuum tube.

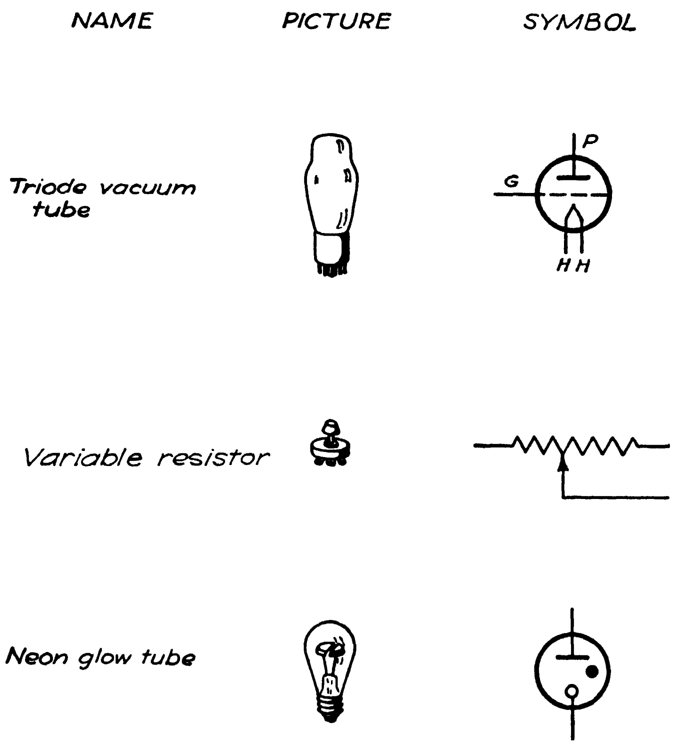


FIG. 65. New symbols used in this chapter.

A three-element tube is selected for you to study first, because it is simple and easy to operate. Later you will study and operate more complicated tubes. This three-element tube has a base for which sockets are readily obtainable and cells or flashlight cells

can be used to heat its filament. You will learn the purpose of each part, or element, of the tube as you do experiments which demonstrate its operation and theory.

In this chapter you will learn the things listed below. In later chapters you will apply the principles as they are used in different circuits in actual receivers and transmitters.

Part 1: How the Vacuum Tube Was Developed
Part 2: How to Examine the Tube and Its Elements
Part 3: How Electrons Can Be Made to Flow through a Vacuum Tube
Part 4: How the Grid, the Control Element, Is Used

The symbols in this chapter are shown in Fig. 65.

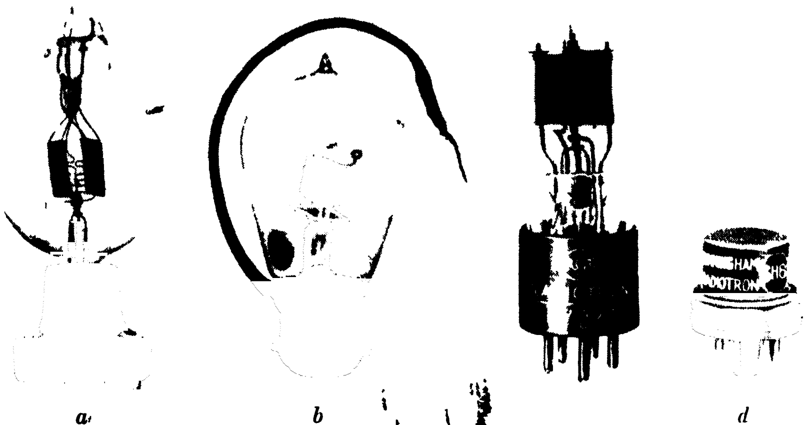
PART 1: HOW THE VACUUM TUBE WAS DEVELOPED

How was the Edison effect used in the development of the vacuum tube? The story is told that while Edison was developing his incandescent electric lamp in 1883, he accidentally made a discovery out of which grew the radio and electronics industry as we now know it. He noted that the inside of the glass was being blackened. To study this effect, he placed a metal shield inside the crude lamp to prevent the carbon thrown off by the hot filament from blackening the glass bulb. Curious, he connected a battery and a sensitive meter to the wires supporting this metal plate and to the filament wires. To his amazement, he found that a weak current flowed through the empty and evacuated space between the filament and the metal plate inside the tube when the filament was lighted. This was impossible, according to any law of electricity then known. Edison, puzzled but too busy with the lamp development to investigate further, contented himself with describing this effect in his technical notes. The *Edison effect*, as it is now known, remained a scientific curiosity without apparent value for the next 20 years.

When young Marconi went to England to develop his wireless invention, he surrounded himself with the outstanding electrical men of that day. One of these men was the late Professor J. A. Fleming, a physicist who had worked with Edison in America at the time he had discovered the Edison effect. While attempting to find a better detector of radio waves than the clumsy ones then in use, Fleming remembered Edison's experiment and adapted

it to his needs. He mounted a filament and a metal plate inside a glass bulb from which he pumped out all the air. Then, when he connected the metal plate, the lighted filament, and a battery to a radio circuit, he found that he had a detector that was rugged and very dependable in its operation. This was the first radio vacuum tube.

Fleming's tube was not very sensitive to weak signals and was little used, because there was no known way of amplifying the



Radio Corporation of America

EVOLUTION OF RADIO TUBE DESIGN

As the tube developed, it became more rugged and more efficient. (*a*) First model of a three-element De Forest audion tube, (*b*) one version of the two-element Fleming valve—forerunner of all vacuum tubes, (*c*) first tube to operate directly from and alternating-current source, thereby eliminating batteries, (*d*) an all-metal tube that contains its vacuum within an iron envelope.

signals picked up by those early radio receivers. Other detectors, such as the crystal, were preferred. In later years, however, engineers learned how to amplify weak signals, so that it became possible to use the reliability and other properties of Fleming's invention to good advantage. Tubes making use of Fleming's principle are used as detectors in many modern radio receivers. They are called *diodes*, a word that is taken from the Greek to indicate that such tubes have two active electrical parts, or *electrodes* the metal plate and the filament.

Another kind of diode tube employing the principle of the Edison effect is widely used in almost all modern radio receivers for changing the alternating current obtained from the house electric-lighting system to direct current for operating the other vacuum tubes in the receiver. We shall see how this is done when we study power-supply units in Chapter 14.

In 1906, some two years after Fleming got a patent on his tube, Dr. Lee De Forest developed an even more interesting tube when he added a third electrode to Fleming's diode detector. De Forest called his new electrode a *grid*, and his new tube came to be called a *triode* to distinguish it from tubes that had more or less than three active electrical parts.

De Forest was an American inventor who, like Fleming, was also searching for a better detector. He experimented with the diode in an effort to improve its sensitivity. He reasoned that he must find some method of controlling the flow of the electrons from the filament to the plate inside the tube.

Because even the lightest piece of metal is millions of times heavier than an electron, De Forest knew that any kind of mechanical device would be unable to move rapidly enough to control the electron flow. Casting about for another method, he hit on the idea of placing a mesh, or grid, of bent wire in the empty space between the filament and the plate of the diode. He allowed the incoming radio signals to act on the grid and found that he had an extremely sensitive detector. He also found that his new tube would amplify signals, and later on it was found that the triode would also act as a generator of radio waves. It would, thus, do most of the wonder-working things that we now associate with electronics and the vacuum tube.

In the next section you will see what the inside of a tube looks like, and then you will perform some experiments to help you find out how vacuum tubes work.

What were the early filaments like? It is a far cry from the fragile handmade filament of carbonized vegetable fiber used in Edison's first electric lamp to the filaments used in modern vacuum tubes, produced by the millions with automatic machinery.

Tungsten was used for the filaments of the early vacuum tubes. But tungsten had two disadvantages: It had to be operated at white heat, and, consequently, the hair-thin filament easily burned

out; also, the storage battery used to heat the filament had to be recharged frequently.

How are filaments made today? Today vacuum-tube filaments are made of three principal materials: pure tungsten, metals coated with oxide, and thoriated tungsten. Pure-tungsten filaments are built into large power tubes for heavy-duty service and are used in broadcasting stations, in high-powered communication service, and for X-ray tubes.

Most of the tubes you find in broadcast-receiving sets and in amateur communication receivers have oxide-coated filaments, or cathodes (see Chapter 15). These filaments are made with a core of Konel metal, an alloy of nickel, cobalt, iron, and titanium. This core is coated with barium or strontium oxides. This highly efficient oxide coating supplies a great many more electrons at a lower temperature than does the pure-tungsten filament, when operating at white heat.

The thoriated tungsten filament is used in the smaller power tubes you will find in your broadcast-receiving set and for public-address sets. This type of tungsten filament contains a small amount of thorium. It is much more efficient as an electron emitter than is the pure-tungsten filament, when operating at a lower temperature. However, it does not equal the efficiency of the oxide-coated filament.

The tube manufacturer recommends a certain filament and plate voltage that has been found by extensive tests to be best for this particular tube. When either the A- or B-battery voltage drops, the action of the set becomes poor.

How are the grid and plate made? The grid of fine wire is formed into a coil and is placed around the filament (see Fig. 66). It is supported by wires fastened into the glass stem. The plate is a rectangular tube of sheet metal, stamped and welded into shape, surrounding both the grid and filament. The metal used in the grid and plate is molybdenum, nickel, or tungsten, sometimes coated with chromium or magnesium oxide to fill the pores of the metal and to keep out air during manufacture. These coatings also act as *getters* to absorb any free gases boiled out of the metal or glass during the final manufacturing stages of the tube.

Why must no gas remain in the tube? The operation of the tube depends upon a very high degree of vacuum and upon this

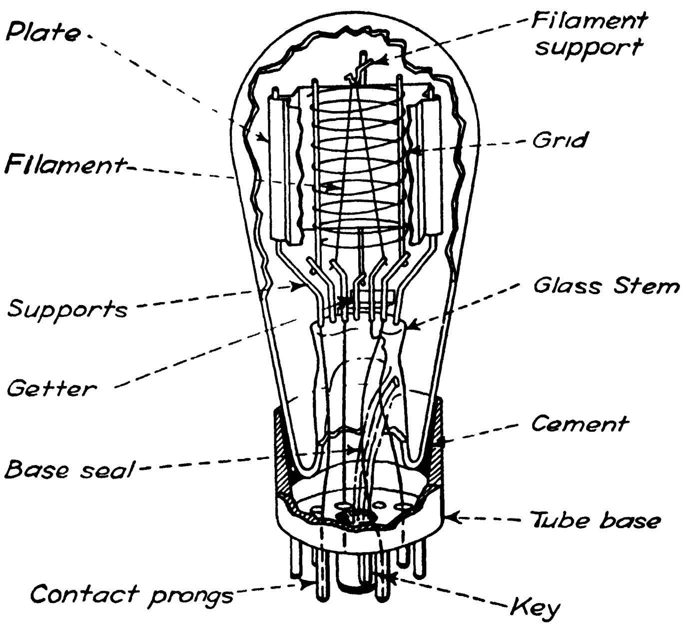


FIG. 66. This is a sectional drawing of a triode tube showing all of its elements inside the cutaway plate. Note the construction and wiring inside the tube base.

degree of vacuum's remaining unchanged. If any air or other gas remains in the tube, its operation becomes so poor that the tube must be discarded. Gas may be detected in the power tubes by a purplish glow around the elements. This glow results from ionization of the air molecules produced by the electrons thrown off from the filament.

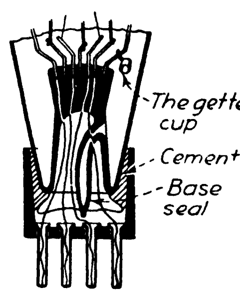


FIG. 67. The base seal. The air and other gas remaining in the tube are removed through the glass tube which is then sealed.

How was air removed? The early method of exhausting or removing the air from a tube was by means of a mercury suction pump. When the tube was exhausted to the highest degree possible, it was sealed at the tip. The easily broken tip seal was soon discarded for a safer seal on the base (see Fig. 67). Any air enclosed in the glass or adhering to the surface of the metal elements of the tube was driven off gradually by the heat of the filament. This caused the tube to become gassy and faulty in its operation.

What is the action of the getter? In modern practice, after the tube is exhausted and sealed, the remaining air is driven off the surface of the metal element and out of the glass by heat generated by a loop of wire carrying a high-frequency alternating current. Heat is generated in the metal while it is in the field of the loop. At the end of the heating, or degassing (de-gassing), process, the heat is increased enough to ignite, or flash, a *getter*, which is a small quantity of magnesium or barium compound in a small metal cup attached to the grid or plate supports. When the getter burns, it takes up the remaining air in the tube.

Questions

1. How do gassy power tubes appear in operation?
2. What steps are used by manufacturers in removing gases from radio tubes?

PART 2: HOW TO EXAMINE THE TUBE AND ITS ELEMENTS

Examine the tube elements. You will feel safer using and handling vacuum tubes if you have seen the inside of the tubes and know something about how they are made. Collect a supply of burned-out tubes to break and study. Break up first any one of the various filament-type triodes to examine their inner construction.

What is the meaning of tube numbers? Many methods of numbering tubes have been tried but none have proven entirely satisfactory. One system is described here. What does 1LE3 mean? What is a 6C5 tube?

For both tubes, the first number gives the approximate filament voltage. The "1" in 1LE3 means that this tube has a $1\frac{4}{10}$- or 2-volt filament. (A "2" indicates a $2\frac{1}{2}$-volt filament.)

The letter was intended to show the purpose for which the tube was designed. The letters in the early part of the alphabet were assigned to detectors and amplifiers, like the 1LE3, the 6C5, and the 6L6. The letter "Z" and a few letters near it were used for rectifiers, like 35Z5 and 5Y3. It later became necessary to assign two letters, like 6SA7, when the number of tubes outran the alphabet.

The last number indicates the number of working connections, exclusive of the shell or metal tube. In any triode there are three elements: the plate, the grid, and a heater filament, requiring two

connections (four active pins). The 6C5 has a plate, a grid, a cathode, and a two-connection heater filament (five active pins).

A 6C5 metal tube is known as a 6C5. A 6C5 tube with a glass bulb and an octal base is a 6C5G. The shorter glass tube of the same type is a 6C5GT.

Break open the tube. Break the glass and examine the different metal parts inside the tube. Each separate operating part

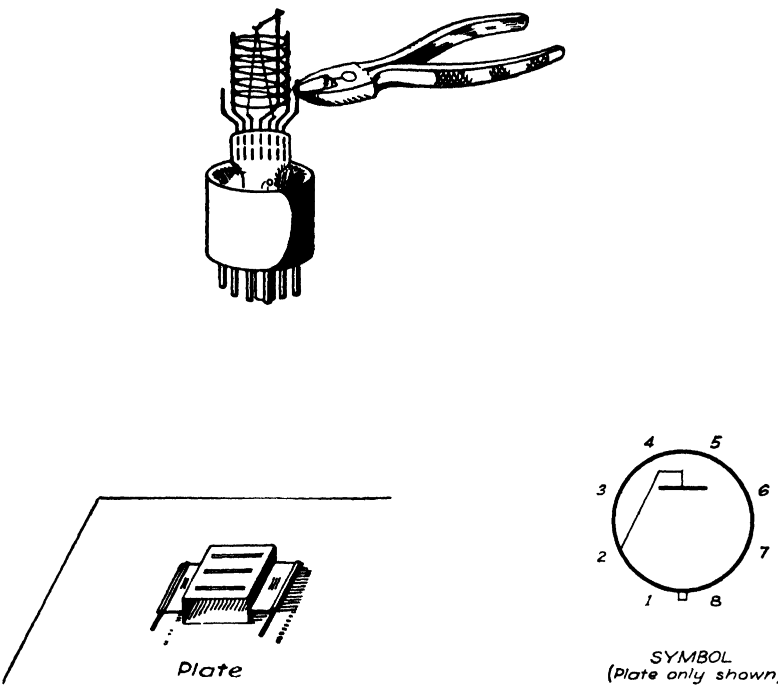


Fig. 68. Break away the glass envelope and examine the elements of the tube. Here the plate has been cut away exposing the grid and filament. Look for the getter as you remove the parts of the tube.

Note the way the plate is shown on the tube symbol.

inside the tube is called an *element*. Now use diagonal cutting pliers to cut the metal-wire supports of the tube elements (see Fig. 68). You will cut each element loose and lay it out on a clean piece of paper for examination and study.

Examine the plate. First cut away the plate supports. The plate is the outer metal part. Note its shape and how it is welded to the support wires.

Trace the wire that runs from the plate to the base prong, or pin. Draw a diagram of the tube base as seen from the bottom of the tube (see Fig. 68). This is a tube symbol. Show on it the number of the pin to which each element is connected.

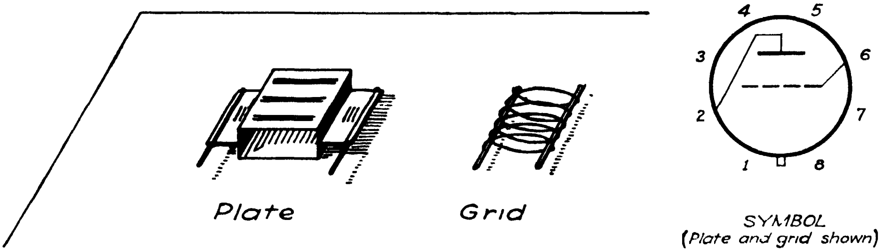


FIG. 69. After you break open the glass envelope of the tube, remove the plate and grid. Lay each piece on a piece of paper for further examination.

Note the way the plate and grid are shown on the tube symbol.

Examine the grid. Next, cut the supports, remove the grid, and examine it. Note the fineness of the grid wire and that turns are spaced the same distance apart (see Fig. 69).

Look closely at the places where the tiny grid coil is welded to the support wires.

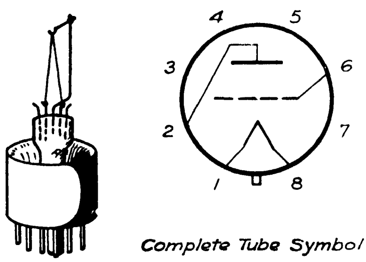


FIG. 70. After the tube elements are cut away you finally come to the filament or what is left of it. The filament is hair-fine.

Note the way the filament is shown in the tube symbol.

Trace the connections from the grid to the base pin. Draw the connection on the symbol. Lay the grid beside the plate.

Examine the filament. The filament wire, which is about 0.002 inch in diameter, is almost too fine to see, and it will probably be broken (see Fig. 70). There will be pieces of it attached to the two supports in the glass, and so you can see its size.

Trace its connections to the base pins, and show them on your tube symbol.

Examine the tube base. Your tube has an insulating base in which are mounted hollow brass pins. The base is made of some suitable plastic or ceramic (porcelain-like) material. Wires run from the tube elements through the hollow pins and are fastened at their ends by drops of solder.

Questions

1. What effect do you suppose poor contact between the pins and the sockets would have upon the operation of a set?
2. Where is the filament placed in a three-element tube?
3. Which element is placed around the filament and next to it?
4. Which element is placed around the other two elements?
5. What two kinds of material were used in the filaments of the older series of tubes?
6. What are some advantages of the material now used in the filaments of tubes?

PART 3: HOW ELECTRONS CAN BE MADE TO FLOW THROUGH A VACUUM TUBE

You are now ready to try the Edison effect that Fleming used in his first diode vacuum tube. You will see the remarkable effect that so amazed Edison and prove for yourself that it actually is possible for electrons to flow through a vacuum.

What is the purpose of this experiment? You are to learn in this experiment these important basic radio principles and practices:

1. How electrons can be made to flow through a vacuum
2. What is one way to control the strength of this electron flow
3. What is good practice in connecting the vacuum-tube circuit, the circuit board, and the batteries
4. How to operate the experiment
5. How to read your results on meters

For this experiment you need the set board described in Chapter 6 and the other parts shown in Fig. 71. The tube, known as a triode, has one more electrode than the two electrodes that Fleming's diode contained, but you will connect the extra electrode in such a way that it will not interfere with your results, and you will thereby save the cost of a tube for which you will have little further use.

You will use a neon lamp to show when current is flowing. The lamp is filled with neon gas that glows with a peculiar red color whenever current flows through it.

Hook Up the Filament Circuit

Step 1. Plug the triode tube into the socket.

Step 2. Connect the set board to the A battery as follows: First, attach wires to the two A terminals on the set board (see

Fig. 71). Then clip the ends of the A wires from the set to the dry cell (see Fig. 72).

Caution. Always connect wires *first* to the set before you connect them to the battery or other source of electric power. You will then be handling electrically dead wires until you actually make connections to the power source. This habit will save you many dangerous shocks later on when you work with sets using high voltages.

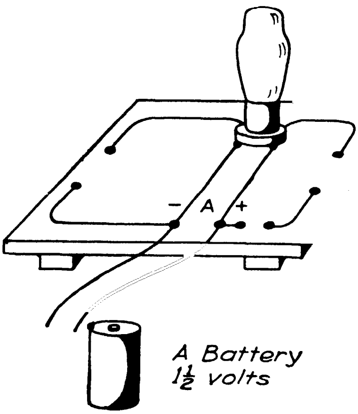


FIG. 71. How to hook up the set. Connect the wires *first to the set*. Why? This is a fine habit to form. Later it may save you unpleasant shocks and burned-out equipment.

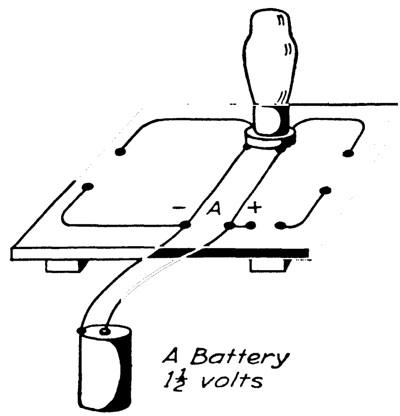


FIG. 72. Connect the wires *last to the battery*. What might happen if the wires were connected *first* to the battery?

Step 3. Check your connections. The polarity must be correct. The filament of the tube will heat, if your circuit is correctly wired. Now disconnect the wires from the battery, remove the tube, and proceed to wire the plate circuit.

Hook Up the Plate Circuit

Step 1. Attach the neon tube. Connect the wires from the output binding posts to the connectors on the neon-tube socket.

Step 2. Connect two 45-volt B batteries in series, and attach a wire from the B-minus binding post to the minus terminal on the B battery. Attach another wire from the B-plus binding post on the set to the B-plus terminal on the battery (see Fig. 73).

Step 3. Remove the effect of the grid electrode from the circuit by connecting a wire between one terminal of the output and one terminal of the input circuits (see Fig. 73).

Test 1: The Electron Flow with the Filament Hot and the Plate Positive

How to Run the Test. Plug the 1LE3 tube into the tube socket and connect both wires to the A-battery terminals. Current from the A battery now flows through the filament. What happens?

The filament temperature can be controlled by a rheostat connected in series in the filament circuit.

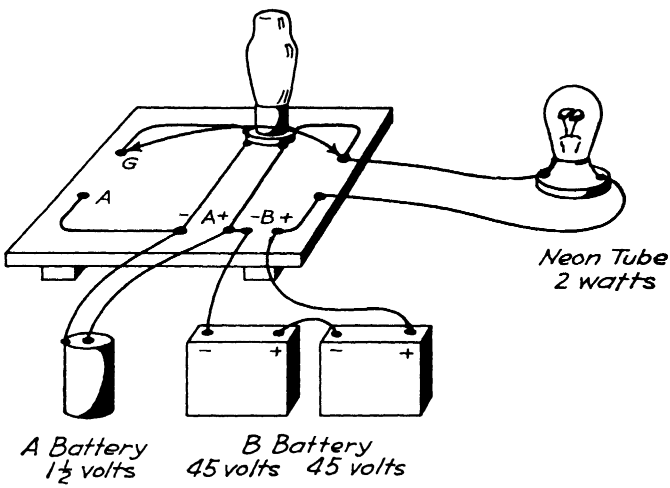


FIG. 73. Finally, connect the B battery to the set. By using this process you avoid burning out the filament by accidentally connecting the B battery to the wrong terminals.

Watch the color in the neon glow tube as you change the filament temperature. What is the effect on the color as the filament temperature increases?

Why It Works. The filament heats when a current from the A battery flows through it. *Caution.* Be sure you have the correct filament voltage. Excessive voltage causes enough current to flow to burn out the filament wire.

As the temperature of the filament increases, the intensity of the glow in the neon tube increases. This means that more current is flowing through the circuit. What is the source of the current which flows through the neon tube?

The filament gives off electrons when heated. It gives off more electrons as its temperature increases. A flow of electrons is called an electric current, so the filament is the source of the electrons which cause the brightness of the color to change.

But how do the electrons get from the filament to the glow tube?

You know that the electrons are negative. The B battery acts as an electric pump and pulls the electrons from the plate. When there are not enough electrons on the surface, we say the plate is *positive.* Unlike charges attract, so the positive plate, which wants electrons, attracts the electrons thrown off by the hot filament.

The electrons reaching the plate flow through the neon tube to the B battery, causing the neon tubes to glow. The electrons are returned by the B battery to the filament through the plate-return wire.

Test 2: The Electron Flow with the Filament Cold and the Plate Positive

How to Run the Test. Remove a battery wire so that no filament-heating current can flow.

The B battery is on when the tube is plugged into the socket. Observe that the neon tube does not glow.

Why It Works. Why does no color show in the neon tube? The neon tube glows only when a current of electrons flows through it.

This test shows that even with the strong pull of the 90-volt B battery, no electrons flow through the circuit. Why is this?

When the A battery is off, the filament is cold. The only purpose of the A battery is to heat the filament. Cold metals do not give off electrons under these conditions. Therefore, no current flows through the tube.

Test 3: The Electron Flow with the Filament Hot and the Plate Negative

How to Run the Test. Turn off the tube filament.

Reverse the two wires in the plate circuit connected to the B battery, so that the negative terminal is now connected to the plate.

Watch the tube color with the filament cold. Observe that there is no plate current flowing.

Heat the filament once more, and again watch for the change in color in the neon tube. Does the neon tube glow? Do electrons flow from the plate to the filament?

Why It Works. There is no colored glow with the filament either cold or hot. No electrons flow through the tube either time. Why is this so?

You expect no colored glow with a cold filament. No electrons are attracted to the plate.

Perhaps, however, you expect a colored glow when the filament is heated. But there should be no glow, because the plate is now negative.

The plate is negative because it has too many electrons. The electrons on the plate repel the electrons in the space charge around the filament. No current will flow under these conditions.

The current will not flow *from* the plate *to* the filament, because no electrons are thrown off the cold plate.

Questions

1. Make a drawing of a tube circuit board. Use a dotted line for the filament circuit, a solid line for the plate circuit, and a double line for the grid circuit.
2. List several ways for attaching wires to the binding posts.

A Summary of the Tube Action

1. Electrons boil off the hot filament. When the filament is heated, electrons boil off its hot surface. You proved that the filament must be hot, because the neon tube glowed in the first test but failed to glow when the filament was cold, in the second test.

The A battery does just one job. It supplies current to heat the filament in order to boil electrons out of the filament material. These electrons form an invisible cloud, called a *space charge*, around the filament.

2. Electrons flow through the tube when the plate is positive. When the positive terminal of the B battery was connected to the plate, the positive plate attracted the negative electrons, and a stream of electrons flowed through the tube to the plate from the space-charge cloud surrounding the filament.

The B battery makes the plate positive, when its positive terminal is connected to the plate, by drawing free electrons from the plate. You may understand its action better if you think of the B battery as an electron pump that pulls free electrons off the plate, thereby making it so highly positive that it pulls electrons to itself from the space charge. The pumping action of the B battery also forces free electrons into the filament.

3. No electrons flow through the tube when the plate is negative. When you made the plate negative by reversing the B battery, the neon tube remained dark, even though the filament was hot. This was because the negative plate repelled the negative electrons in the space charge and prevented their moving across the empty space inside the tube.

4. Electrons flow through the tube in only one direction. Electrons flow from the filament to the plate. If we make the plate negative by reversing the B battery, the plate repels electrons in the space charge. None will flow to the plate. The neon tube remains dark. You will find many valuable uses for this electron stream in both radio receiving and transmitting circuits.

Questions

1. List the parts which make up the filament circuit.
2. List the parts which make up the plate circuit.
3. Why should the battery be the last part you connect to the set?
4. What advantages has the neon tube over a meter in this hookup?
5. Would electrons boil off a hot filament as readily when the tube is filled with air as when it is evacuated? Explain.
6. If the B battery is disconnected, what happens to the electrons in the space charge when the filament is allowed to cool off?

PART 4: HOW THE GRID, THE CONTROL ELEMENT, IS USED

What Is the Purpose of the Grid in a Vacuum Tube? When De Forest bent a piece of wire into a rudely shaped grid and sealed it into his tube, he made possible the radio industry as we now know it. In the history of this man's life is a fascinating chapter in the development of radio—the story of his work leading up to the revolutionizing grid. It is well worth reading.

De Forest knew that like charges repel each other and unlike charges attract. He knew that he could force free electrons onto the wire grid by attaching a battery to the ends of the wires outside of the tube. He reasoned that free electrons on the grid wires would affect the electrons streaming across the space inside the tube.

Grid-control Experiment

Now set up an experiment and see how this grid can control the flow of electrons through the tube. Use the same tube circuit board that you used in studying the vacuum tube (see Fig. 74).

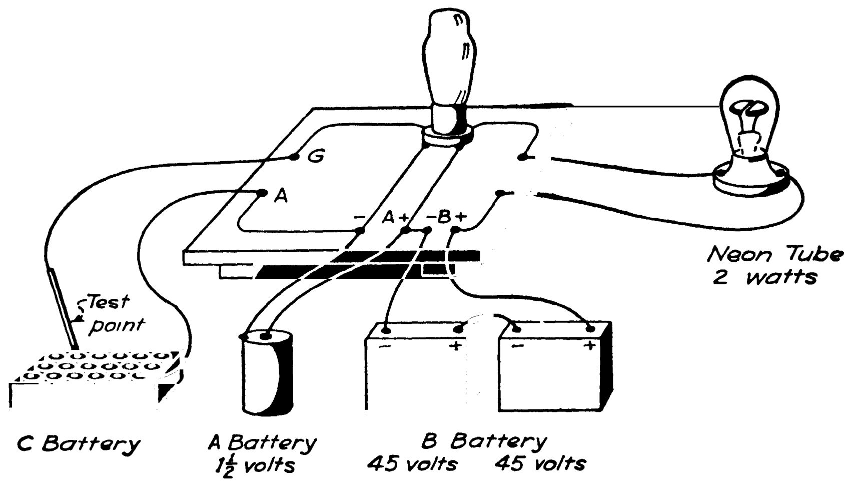


FIG. 74. This is the way to hook up the tube board for the grid test with grid negative. For the test with the grid positive, reverse the C battery.

Hookup

Step 1. Attach the filament A battery. Use a 1½-volt dry cell.

Step 2. Attach to the output binding posts the 1-watt neon glow tube.

Step 3. Attach 90 volts of B battery to the B binding posts. This can be two 45-volt B batteries connected in series.

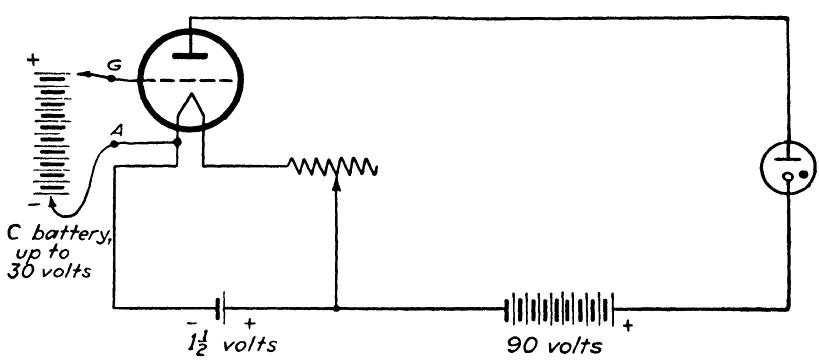


FIG. 75. The schematic diagram of the circuit used for the grid test.

Test 1: When the Grid Is Made Negative

Step 1. Attach test points to the A and G posts on the set board (see Figs. 74 and 75). Clip the A-minus connecting wire to the plus end of the C battery.

Note. Make the C battery from a group of 20 flashlight cells wired in series. Build a small box for these cells.

Step 2. Touch the test point from the G post to the first flashlight cell at the C-plus connecting wire. Move this test point from cell to cell. This will gradually make the voltage on the grid increasingly negative. Watch the brightness of the neon glow tube change. Continue until you have connected all of the flashlight cells into the circuit, at which time the test point will be placed as in Fig. 74.

Why It Works

When you touched the test point from the grid to the C battery at a point several cells away from the plus terminal, the dimming of the neon tube showed what was happening. The C battery forced a few free electrons onto the grid. These electrons, which could not leave the cold grid, repelled electrons passing near the grid on their way from the filament to the plate. As you moved the test point to the next cell of the C battery, making the grid more negative, you finally discovered that the glow in the neon tube disappeared. This showed that so many free electrons were on the grid that they were able to repel all passing electrons so strongly that none reached the plate. Their repelling effect was stronger than the pull of the positive plate. When this effect occurs we say that the tube is *biased to cutoff*. This means that the grid has been made *negative* enough to stop completely the flow of electrons from filament to plate. When a voltage is applied to the grid by means of a C battery, we say that we have *biased the grid.*

Rule. A negative voltage on the grid reduces or may even completely stop the flow of electrons from filament to plate.

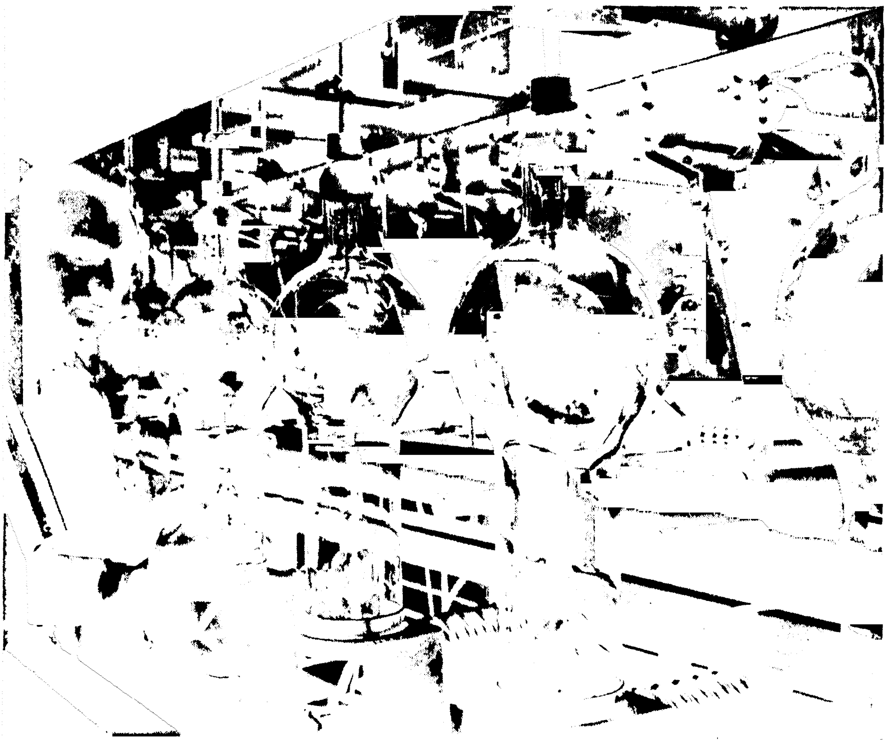
Test 2: When the Grid Is Made Positive

Step 1. Move the A-minus test point connection so that it is attached to the negative end of the group of C batteries.

Step 2. Now touch the G-post test point to the first flashlight cell at the C-minus connecting wire. Again move the test point from cell to cell until all the battery is connected in the circuit. This will gradually make the voltage on the grid increasingly positive. Watch the glow tube as before.

Why It Works

When you reversed the connections to the C battery and made the grid *positive*, the battery pulled the free electrons from the grid, leaving it more positive than it was before. The positive grid then attracted electrons near it in the space charge and set up



Westinghouse Electric and Manufacturing Company

HIGH-VOLTAGE RECTIFIER TUBES

Electronic tubes such as these have undergone many improvements in recent years. In this installation, these high-voltage rectifier tubes change alternating current into the direct current used for radio transmission. Automatic relays are used for changing tubes without interrupting broadcasting.

two effects: (1) In spite of the fact that electrons in the space charge were attracted toward the grid, the positive plate was strong enough to pull most of the electrons through the grid to itself before they touched the grid. The pull exerted by the positive grid added to the pull of the positive plate and caused more electrons to flow. On their way to the B battery, these electrons

made the neon tube glow more brightly. (2) A *few* electrons near the grid in the space charge jumped onto the positive grid. The grid acted like a small plate. It collected very few electrons because it was much less positive than the plate and because the area of the wires was so much smaller than the area of the plate.

Rule. A positive voltage on the grid increases the flow of electrons from filament to plate without drawing very many passing electrons to the grid.

Questions

1. Will doubling the grid voltage also double the plate current?

2. Suppose you connect enough batteries in the grid circuit to shut off the plate current completely. What then would happen if you doubled the plate voltage?

3. If a positive grid attracts electrons, why do most of the electrons go past the grid to the plate? Suggest a way to cause most of the electrons to stop on the grid.

Technical Terms

A battery—Either dry cells or a storage battery used to heat the filament.

ampere—The word used to indicate the amount of flow of electricity. The ampere is the unit of the flow of electricity.

Bakelite—An insulating material, a plastic.

base pins—Small brass tubes set in the tube base. The pins are arranged so that they will fit into the tube socket only in the correct way. Wires from the tube elements pass through the pins and are soldered to the tips of the pins.

B battery—A high-voltage battery used in the plate circuit to make the plate positive.

C battery—A medium-voltage battery connected in the grid circuit to keep the grid negative and thus prevent distortion.

conductor—A wire, metal, or a solution through which a current of electricity will flow.

diode—A two-element vacuum tube. A diode contains a filament and a plate.

element—The operating parts of a vacuum tube are called the elements, *e.g.*, the filament, the grid and the plate.

filament—The fine wires in the vacuum tube which, when heated, supply the free electrons in the tube.

getter—A small metal cup or plate filled or covered with magnesium and welded to the plate support, used after the air is exhausted from the tube to get, or absorb, all remaining air or gas driven out of the glass and metal by heating.

glass stem—The part of the glass in a vacuum tube that supports the tube elements.

grid—A coil of fine wire supported between the filament and the plate of the tube. The grid controls the flow of electrons through the tube.

grid circuit—The grid of the tube, the tuning circuit, and the grid-return wire attached to one filament lead; the input circuit of the tube.

Nichrome—A high-resistance wire made of alloy metal.

octal—A word meaning eight. An octal tube has eight pins.

ohm—A word used to indicate the unit of resistance. An ohm represents a resistance through which 1 volt can force 1 ampere of current. This is known as Ohm's law.

plate circuit—The output circuit of the tube, which consists of the plate, the earphones, the speaker or amplifying transformer, the B battery, and the plate-return wire connected to the tube filament.

plate current—The current, generally a few milliamperes, flowing in the plate circuit.

plate return—The wire connecting the plate circuit to the tube filament.

space charge—The cloud of electrons surrounding the heated filament.

thoriated filament—Filaments of tungsten to which traces of thorium have been added during manufacture.

thorium—A metal used in filaments to produce a more plentiful supply of electrons.

tip seal—The point on the older glass tubes where the air was removed from the tube. This seal broke easily and was later replaced by the base seal.

triode—A three-element vacuum tube. A triode contains a filament, a grid, and a plate.

tungsten—A hard metal of high resistance used in tube filaments.

vacuum—The absence of gas. As much gas as possible has been removed from vacuum tubes.

CHAPTER 8

WAVE-FORM PICTURES

The action of alternating-current surges and the flow of direct currents in radio and in electrical circuits are often difficult to explain in words. But you can draw pictures which show current action that would take many words to explain.

In this chapter you will learn what wave-form pictures of simple alternating and direct currents look like and how to read their meaning.

If a cathode-ray oscilloscope is available, you can see the actual wave shape of a current as it is traced out by a moving colored line. This makes the study of the simple wave forms much more vivid and clear.

You can also study the electron action in radio transmitting and receiving circuits by using wave-form pictures.

In this chapter you will learn the following things:

Part 1: How to Study Electron Flow by Wave-form Pictures
Part 2: How to Use the Oscilloscope to Study an Alternating Current
Part 3: How to Read and Draw Wave-form Pictures
Part 4: How Strength, or Amplitude, Is Shown on the Oscilloscope
Part 5: How High and Low Frequencies Are Shown on the Oscilloscope
Part 6: How a Pulsating Direct Current Is Shown on the Oscilloscope
Part 7: How Wave Forms of Rectified Alternating Current Are Shown

PART 1: HOW TO STUDY ELECTRON FLOW BY WAVE-FORM PICTURES

Why are wave-form pictures used? As we have said, it is often easier to use a picture, or diagram, than to explain in words the action of the electrons flowing in even the simplest radio circuits.

In some cases this action can be shown clearly by means of electron-flow arrows on a diagram. But to show the action of electron currents as they change in direction from moment to moment, it is customary in electrical and radio discussions to

depend on diagrams called *wave-form pictures.* A student must be able to read many kinds of diagrams and to understand their meaning.

How are wave-form pictures formed on the oscilloscope screen? Of the many instruments used to introduce the nature of electricity to a student, none has been as clear and as valuable as the cathode-ray oscilloscope (see Fig. 76). The wave forms shown by the oscilloscope make clear the action of electricity in radio circuits and in the simple circuits of the ordinary electrical apparatus used in the home and elsewhere.

When the oscilloscope is properly adjusted, the electron stream traces on the screen of the tube lines or curves that show in clear

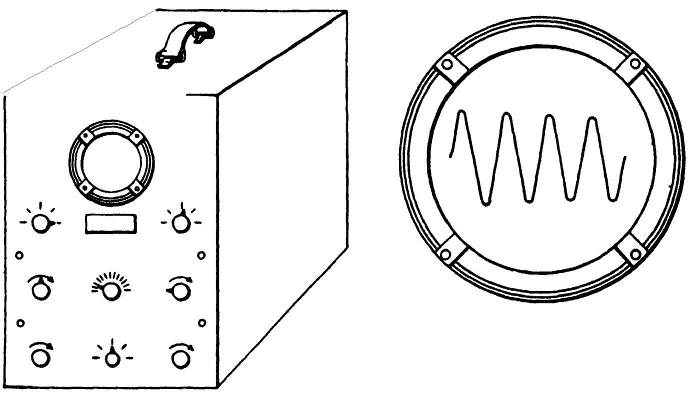


FIG. 76. The cathode-ray oscilloscope shows wave-form pictures.

form the action of the electrons as they flow in the circuit that is being studied.

How much simpler it is to study these wave forms than to use diagrams or wordy explanations! The trace of the line or of the curve can be seen and studied at your pleasure merely by making proper attachments to the circuit and by turning on the oscilloscope.

How are the oscilloscope wave pictures used? The diagrams in this chapter show the actions of electrons flowing in different types of circuits and also the wave shape of the direct-current and alternating-current flow.

The diagrams in this chapter are drawn from the traces of the cathode-ray oscilloscope. The traces have been taken apart for study and have been simplified. You will study, then, parts of

wave-form pictures redrawn (re-drawn) from the curves traced on the oscilloscope screen by the millions of dancing electrons.

The cathode-ray oscilloscope shows the *changes* in voltage that occur in the part of the radio circuit to which it is attached. It

Hytron Radio & Electronics Corp.

WAVE-FORM PICTURES

This engineer is examining the wave-form picture of an operating circuit.

shows these changes as they take place, unless they occur so fast that it is impossible to see them. Changes which repeat themselves in a steady pattern are easy to see and to study on the "scope."

What is an oscilloscope? We shall now give a greatly simplified explanation of the cathode-ray oscilloscope: It is an instrument arranged to cause a tiny *fluorescent* spot to move across a screen, forming the lines and patterns that we call wave-form pictures. In the early oscilloscope a tiny mirror was moved by current flowing through coils suspended in a magnetic field. A beam of light, reflecting from the mirror, "drew" on a screen the lines of the wave-form pictures being studied. In the more modern cathode-ray oscilloscope, a moving beam of electrons in the cathode-ray tube draws a glowing fluorescent trace to show the wave form.

The cathode-ray oscilloscope has come into wide use in recent years as an instrument that gives an instant-by-instant picture of the action of the electron flow at any point in a radio set. The cathode-ray oscilloscope is not particularly new, but the wide use of the same type of tube in television and in radar during the war did much to popularize this instrument and to increase its use by radio servicemen, schools, and experimenters.

How will you use the oscilloscope? At this early stage in your study of radio, you will learn only the general operating principles of the oscilloscope and how to attach it to simple radio and electrical circuits. You will learn to use the oscilloscope as a new form of meter. You will also learn to interpret the straight and curved line of the wave pictures it produces.

The electron beam, which has practically no weight, can be made to follow the current or voltage changes in a circuit even though they occur millions of times per second.

What can wave pictures tell you? Two simple wave-form pictures may give you some idea of the ease with which even complicated actions of electrons in a circuit can be represented as a line on the screen of the oscilloscope.

The straight-line picture of Fig. 77 shows you a steady direct-current voltage that is five units strong. The wave picture in Fig. 78 tells you that the direct-current voltage is changing in strength at a regular rate. It regularly becomes stronger, weaker, stronger, and so on.

What are the operating principles of the cathode-ray tube? Electrons, released by a hot cathode, are shot through the long tube by high voltage (see Fig. 79). The electrons are focused into a ray, or beam, as they stream through electrically

charged metal cylinders, in much the same way that light is focused into a beam by lenses.

The electron beam strikes the fluorescent willemite coating, or screen, on the tube and makes a glowing green spot of

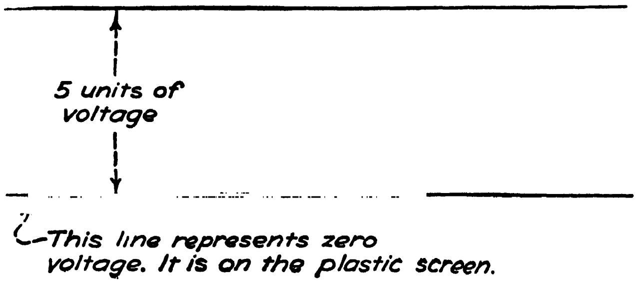


FIG. 77. This is the wave-form picture of a steady, direct-current voltage.

light, in much the same way that light is produced in fluorescent lamps. The coating glows, or fluoresces, at the spot where the beam strikes, and the spot moves when the beam moves. Some tubes are made so that the glow is bright enough to be photographed.

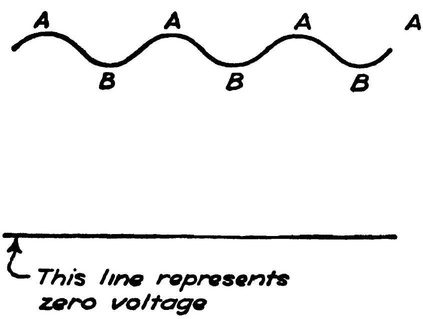


FIG. 78. This is a wave-form picture of a direct-current voltage that is changing in strength at a regular rate. The zero voltage line is on the graduated screen that covers the face of the cathode tube.

The beam is swept across the screen. A special electrical circuit called a *horizontal sweep circuit* rapidly moves, or sweeps, the beam back and forth across the screen to form a straight colored line. This sweep circuit is connected to the plates inside the tube, so placed that the electron beam passes between them (see Fig. 80). The circuit is arranged so that voltages produced by the sweep circuit force electrons onto one plate and pull them off the other. The surplus electrons on the negative plate repel the electron beam, while the other plate, which is positive, attracts the beam. The sweep-circuit voltage changes direction at a rate which can be varied from about sixty times to several thousand times a second, so that the beam is swept back and forth at the same rate. Knobs on the

instrument panel enable you to control the number of times per second that the spot sweeps across the screen. Another knob controls the length of the line across the screen. Other knobs control the intensity and focus of the spot.

The beam can also be raised or lowered. Another pair of metal plates is set in the tube above and below the electron beam

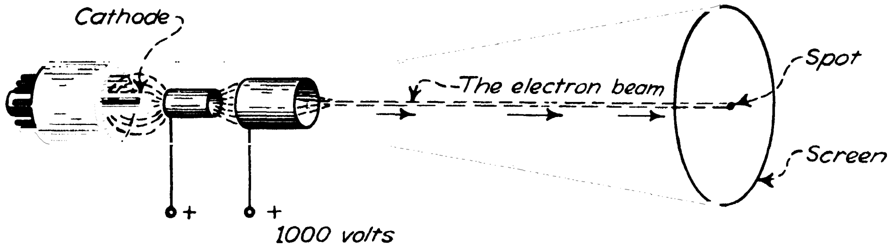


FIG. 79. Parts of a cathode-ray tube. The cathode element furnishes the electrons, another element accelerates them, and another focuses them into a beam that becomes visible when it strikes the coating on the screen.

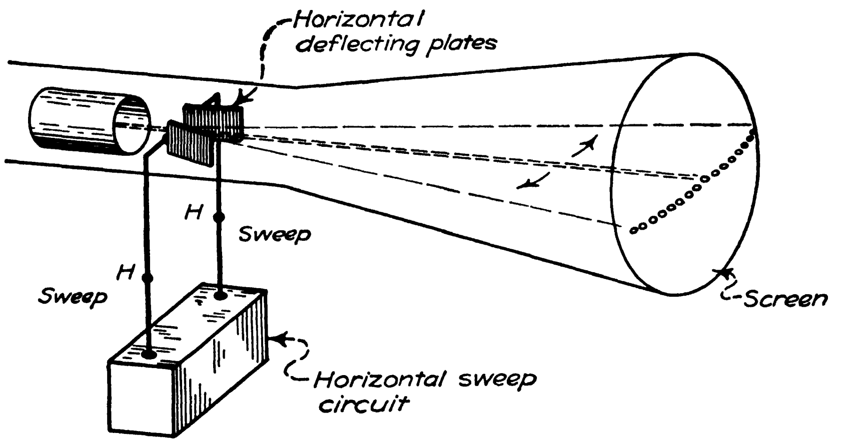


FIG. 80. These flat metal plates are set into the tube so that the electron beam passes between them. The plates are connected to a sweep circuit, which drives electrons on and off the plates and moves, or sweeps, the beam back and forth across the screen.

(see Fig. 81). Connections between these two plates and the part of the circuit you are studying are made through binding posts on the panel of the scope. When the connections are properly made, electrons on these plates raise or lower the beam. A voltage difference across the part of the circuit being studied forces electrons onto, let us say, the lower plate and makes it negative. This

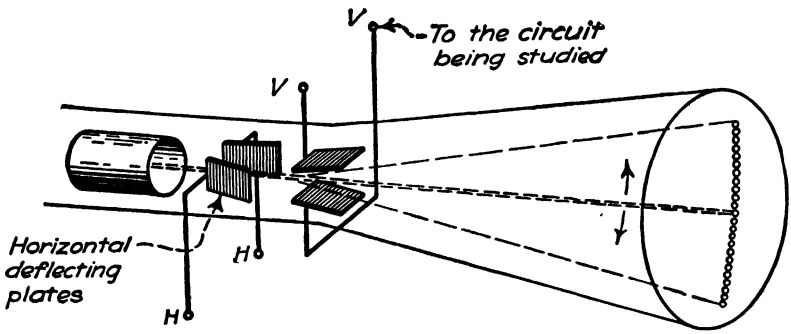


Fig. 81. There are also a pair of plates set vertically above and below the beam. These plates are connected to the binding posts on the front of the oscilloscope. When you connect a circuit to them, the spot is moved up and down by the changing electron pressure on the plates.

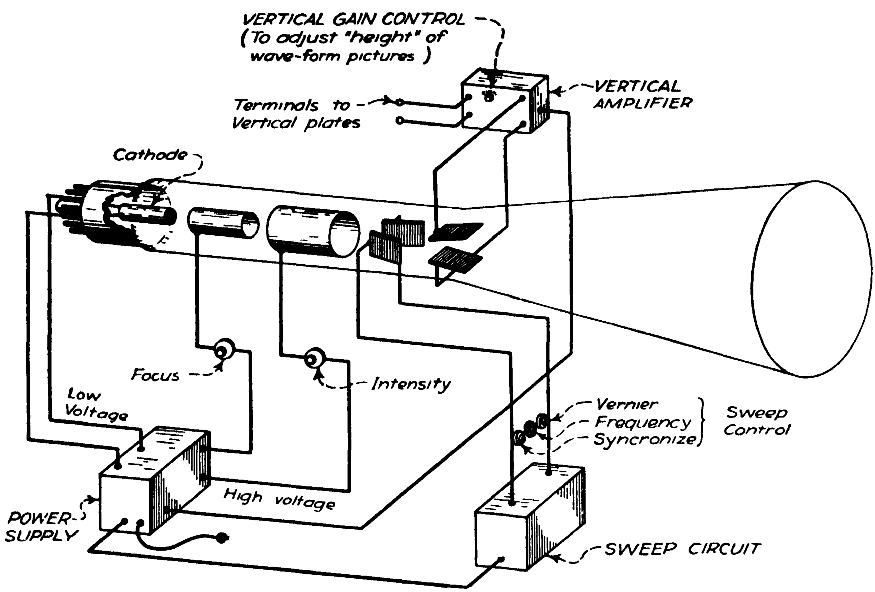


Fig. 82. A simplified diagram of the cathode-ray oscilloscope. Note the principal controls shown in the diagram.

repels the beam, and at the same time the electrons are pulled off the upper plate, which becomes positive and attracts the beam, so that it moves toward the upper plate. If the direction of electron flow changes in the circuit you are studying, the voltage on the plates will change and the beam will drop. The line on the screen in Fig. 81 is being traced by a rapidly changing voltage on the vertical deflection plates.

The complete simplified circuit of the oscilloscope is shown in Fig. 82.

Both voltage and current operate the oscilloscope. As was just explained, a voltage difference, or voltage drop, across some part of a circuit is used to operate the cathode-ray tube. According to Ohm's law, the voltage drop is found by using the formula $E = IR$.

Therefore, when you connect the leads from the scope to the two ends of a resistor in the circuit you wish to study, the movement of the electron beam corresponds to the changes in voltage (E) across the resistor. But since the resistor value remains the same, the voltage drop follows the current-flow changes in this part of the circuit.

So, indirectly, the motion of the electron beam measures the changes in current strength, that is, the changes of electron flow, in either a direct current or an alternating current.

Note. When a direct-current voltage is connected to the V binding posts, the spot may move upward or downward for a moment and then return to the reference line, or zero position. This happens because a small series fixed condenser is connected in the circuit and the line moves while the condenser is charging, then returning to zero. In some oscilloscopes this condenser is omitted.

PART 2: HOW TO USE THE OSCILLOSCOPE TO STUDY AN ALTERNATING CURRENT

What is an alternating current? As you will recall, any electrical current is a flow of free electrons through a wire or other conductor. In a direct current the electron flow is in one direction, but in alternating current the electrons flow first in one direction, then in the other. The oscilloscope can show clearly how the flow of the electrons in an alternating current changes from moment to moment.

Examine the graduated screen. Look at the removable screen that is used to cover the face of the tube in most oscilloscopes. A set of evenly spaced lines is printed on the transparent plastic cover and serves much the same purpose as the numbers and marks on a meter scale. You can use the graduated screen as the base lines of a graph. The heavy lines are the X and Y axes (see Fig. 84).

You will learn later how this ruled screen makes it possible to use the oscilloscope as a voltmeter.

Show the alternating-voltage wave on the oscilloscope. You can use the oscilloscope to show the wave-form picture of an alternating voltage by connecting the secondary of a toy transformer to the binding posts that are connected to the vertical-deflection plates on the cathode-ray tube (see Fig. 83).

We know that the electron flow in the wires of the circuit feeding the transformer is constantly changing. As the rotor in the alternating-current generator at the powerhouse turns, it sends the electrons flowing in one direction through the power wires. Then it causes them to flow in the other direction. An electron flow in one direction followed by a flow in the opposite direction

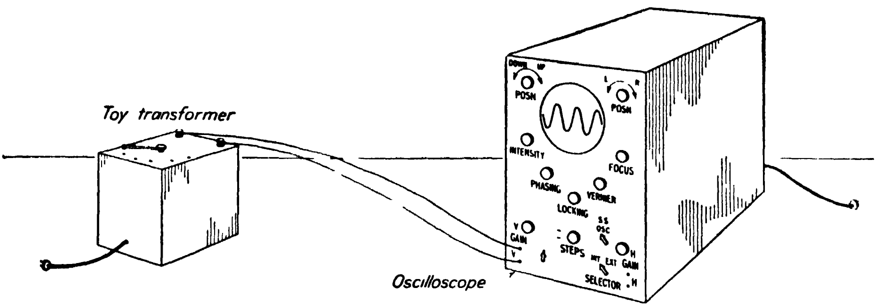


FIG. 83. Using an oscilloscope to study the wave form of the alternating current.

is called a *cycle*. Each half cycle, where the electron flow is in a single direction, is called one *alternation*.

Now do an experiment to show wave-form pictures of one alternation and one cycle on the oscilloscope.

Experiment. You will now use the oscilloscope to show the action of the 60-cycle alternating current. Names of controls vary on different oscilloscopes. Follow the instructions that fit your oscilloscope.

Step 1. Attach wires from toy transformer to V input of the oscilloscope (see Fig. 83). As a safety precaution make these connections before plugging in transformer or oscilloscope to power outlets. This prevents a spot being burned on the screen.

Step 2. Now plug in the transformer and the oscilloscope. Turn on the power switch of the oscilloscope.

Step 3. Adjust the V. GAIN and the H. GAIN controls to get a pattern on the screen. Adjust INTENSITY and FOCUS controls to get a bright, sharp pattern.

Step 4. Set selector switch to "INT."

Step 5. Set the sweep-range STEPS control to the range that includes 60 cycles.

Step 6. Set the sweep switch (above selector switch) to SS OSC.

Step 7. Adjust the vernier to get a single sine wave.

Step 8. Adjust LOCKING control to hold sine wave pattern.

Step 9. Center the sine wave pattern by adjusting the UP-DOWN and the L-R positioner controls.

This is the wave picture of the 60-cycle alternating voltage. This voltage is the sort delivered by many electric-light plants.

Questions

1. What causes the glowing lines to appear on the end of a cathode-ray tube?
2. What are wave pictures?
3. What is the purpose of the sweep circuit in an oscilloscope?
4. What is the purpose of the two metal tubes in the small end of the cathode-ray tube?
5. What is an alternating voltage?
6. Is there a steady flow of electrons in an alternating current?
7. Do the electrons in an alternating current always flow in the same direction?

Why It Works. But how do the electrons raise and lower the spot? When voltage caused by the electron flow in the circuit

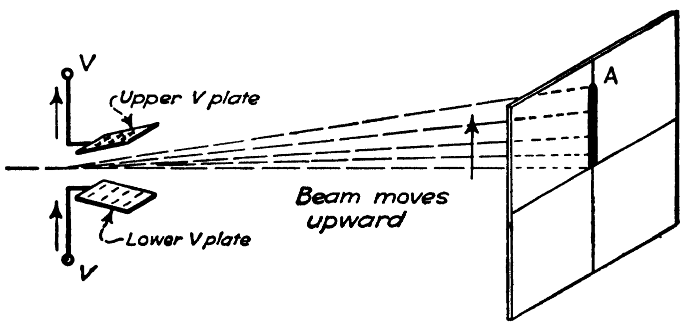


FIG. 84. The beam moves upward when electrons are forced on the lower plate and electrons are pulled off the upper plate. The electrons on the lower plate push up the beam and the positive upper plate pulls up the beam.

being studied makes the upper vertical-deflection plate of the cathode-ray tube positive, the lower plate of the pair becomes negative. This forces the beam upward. Operating alone, these two plates would make the spot move up to point *A* on the screen, thus tracing a vertical line (see Fig. 84). The alternating current

in the transformer causes a voltage that is constantly changing across the vertical-deflection plates. At first it forces a few electrons onto the lower plate and pulls the same number off the top plate. The cathode-ray beam begins to rise. As more electrons are forced onto the lower plate, the line rises higher. The spot rises to a *peak*, or maximum value, and then begins to drop back to zero.

The sweep also moves the spot *across* the screen: At the same time that the electrons raise or lower the spot, the sweep circuit

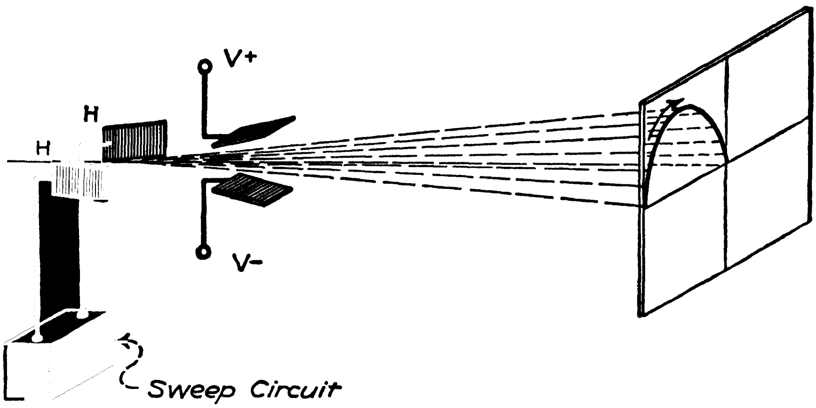


FIG. 85. Now the combined effects of the push and pull of the *H* plates and the upward and downward pulls of the *V* plates form this half of the sine curve or sine wave.

connected to the horizontal-deflection plates is pulling the spot back and forth, left and right.

Settings of knobs (usually three of them) control the rate at which the sweep circuit pulls the spot to and fro across the screen. Properly set, they cause the electrons to surge on and off the two horizontal-deflection plates in step with the surging of the electrons on the vertical-deflection plates. While the spot is being pulled halfway across the screen by the sweep, it is also forced upward by the voltages across the two *V* plates during the first part of the half cycle and then dropped back to zero at the end of the half cycle. The line in Fig. 85 shows where the sweep circuit and the *H* plates move the beam.

During the second half of the cycle, the generator is pulling the electron flow in the circuit in the opposite direction. In the tube the electrons now are forced *onto* the upper plate and are pulled

off the lower *V* plate (see Fig. 86). The beam is now pulled downward in a curved path. It reaches a peak and then returns to the zero line.

Why does the line stay on the screen? The whirling generator at the power plant that supplies your alternating current runs steadily, forcing the electrons in the circuit to flow first in one direction, then in the other.

The sweep circuit, which you adjust by means of the frequency, synchronization, and vernier controls (see Fig. 82), returns the

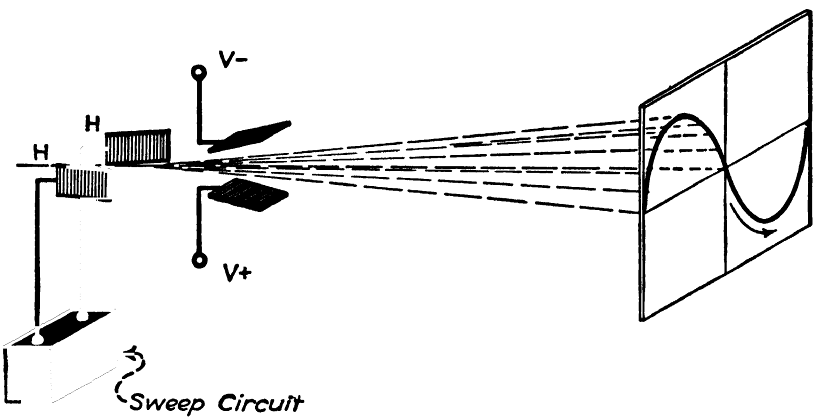


FIG. 86. When the current in the transformer reverses, it forces electrons on the upper plate, pulls them off the lower plate, and causes the beam to drop. But the effect of the sweep, acting at the same time, combines to form the lower loop of the sine curve.

beam to the starting position at the beginning of the second cycle, and the glowing spot travels back over the same path on the screen. This gives you a wave-form picture of the steadily repeating electron flow in the circuit you are studying, and it shows how the strength of the voltage from the transformer changes from instant to instant.

PART 3: HOW TO READ AND DRAW WAVE-FORM PICTURES

After you make a drawing of a simple sine wave, you can understand how the patterns you observe on the oscilloscope screen describe the changing electron flow that goes on in a radio circuit.

You will use curving lines to show the changes in strength of current, or voltage. When the line slips *away* from the time line, the voltage is getting stronger. When the line is drawn *toward*

the time line the voltage is getting weaker. No electrons are flowing through the wire at the node point, or point at which the curve touches the time line.

Draw the time-measuring line. You will draw a horizontal line called the *time line* (see Fig. 87). On the time line you will mark off equal spaces which show the time required for each alternation of the alternating current. In a 60-cycle current the first point

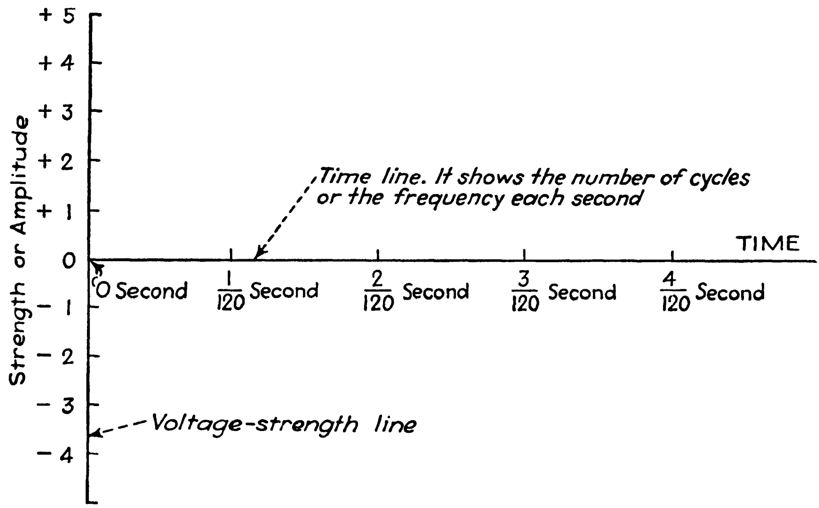


FIG. 87. Base lines for wave pictures with measurements.

marked off will represent $\frac{1}{20}$ second between the zero mark and the end of the first half cycle.

Draw the amplitude- or strength-measuring line. Now you need a line to use for measuring the strength of voltage surges. You will draw a vertical line for this purpose (see Fig. 88). It is called the *amplitude*, or strength, line, and it, too, is marked off in equal spaces that you will use to represent variations in amplitude, or strength.

Draw a positive voltage loop. The wave-form picture in Fig. 88 shows a loop of voltage. At point *A* the electron flow has just begun. At point *B*, the peak of the curve, the electrons are exhibiting the maximum amount of flow. At point *C* on the curve the current has almost stopped flowing.

Let us agree that electron flow in one direction in a wire will be called *positive* and flow in the opposite direction *negative*.

It has become standard practice to draw the positive loops above and the negative loops below the time line. This is done only as a matter of convenience.

The node is a point of no current flow. At the $\frac{1}{120}$-second point on the time line, the current flow has momentarily stopped. The

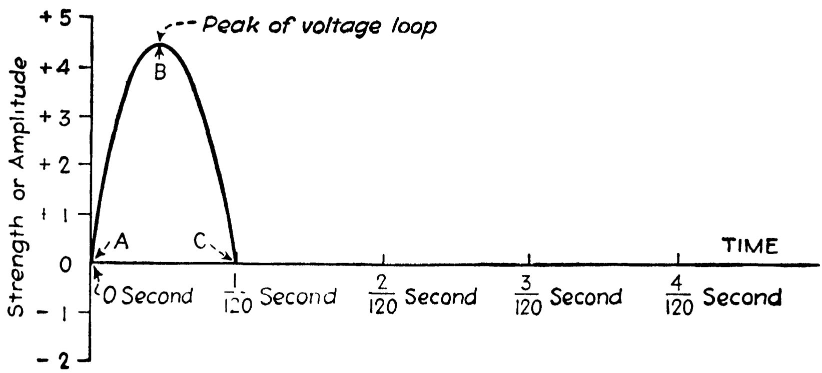


FIG. 88. A *positive* voltage loop.

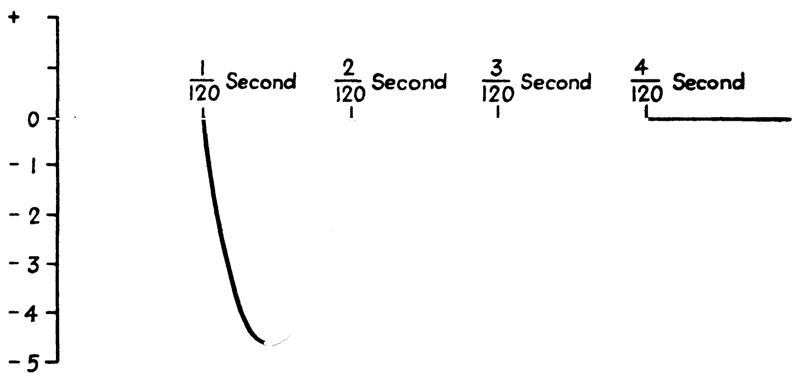


FIG. 89. This diagram shows the *negative* loop. It is the second alternation of current.

generator at this period is driving no free electrons through the circuit wires. So just for an instant, no current flows. Then the electrons start their return journey in the opposite direction. The point on the time line where no electrons are flowing is called a *node*.

Draw a negative voltage loop. Now, in the wave-form picture in Fig. 89, you see much the same electron travel occurring during the next $\frac{1}{120}$ second as you saw in Fig. 88, for the time interval between 0 and $\frac{1}{120}$ second, but here the current flow, or electron

flow, is in the opposite direction. You draw the curve as in Fig. 89, but the loop is now *below* the time line instead of above. This curve is called a negative loop, or a negative alternation of voltage.

What is a cycle? In Fig. 90 you see the wave-form picture of a complete single cycle. First there is a positive loop, where the electrons flow in one direction; then the node point, where no current flows; and finally a negative loop, where the voltage drives the current in the opposite direction. The three parts combine to

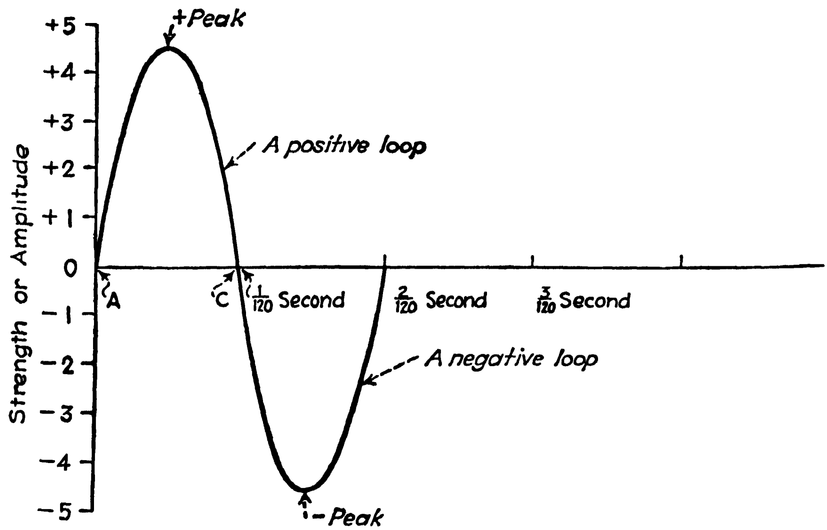


Fig. 90. This diagram shows a complete *cycle* of alternating current. Note that one cycle consists of a positive alternation and a negative alternation.

form a picture of two alternations, which make one complete electron round trip, or one complete cycle of alternating current. The mathematical name of this curve is a *sine wave*.

Questions

1. What is the purpose of the straight horizontal line in a wave-form picture?
2. What is the purpose of the straight vertical line in a wave-form picture?
3. Is a positive voltage represented above or below the horizontal line?
4. Where is the negative part of the cycle represented?
5. One loop above the line represents what part of an alternating current?
6. A wave-form picture including one loop above a line connected to one loop below the line represents what part of an alternating-current wave picture?
7. What are electrons doing at the instant shown by the node in a wave-form picture?

PART 4: HOW STRENGTH, OR AMPLITUDE, IS SHOWN ON THE OSCILLOSCOPE

The amplitude of the wave, or the maximum strength, is shown by the height of the curve on the screen of the oscilloscope. This is shown by the following experiment:

Experiment

Step 1. Connect the 6-volt terminals of a toy transformer to the vertical posts on the oscilloscope.

Plug the cord from the transformer into an alternating-current outlet.

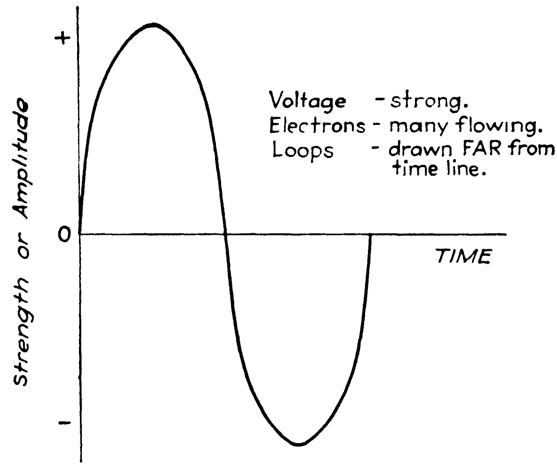


FIG. 91. This wave picture shows a strong voltage. It has a high amplitude.

Step 2. Adjust the height of the sine wave to ½ inch by means of the vertical-gain control.

Step 3. Reset the toy transformer to 12 volts. Measure the height of the loops. They should be exactly twice as high as in Step 2, or 1 inch high. (Do not change the setting of the gain control.)

Step 4. Repeat for different voltages. Check the height of the loops for each voltage.

The curves shown in these diagrams have the same shape for both current and voltage. Now examine some wave-form pictures to see how they show voltages of different strengths. Figure 91 shows a wave-form picture of a strong voltage.

The same scheme is used for showing a weak voltage. You

find that the sine wave of a weak voltage may be drawn as easily as for a strong voltage by making the loop low (see Fig. 92).

Now turn on the light in the room in which you are sitting. You can use an oscilloscope to watch the changing voltage of the alternating current that lights the lamp overhead. You can see that the electron flow is caused to surge back and forth rapidly,

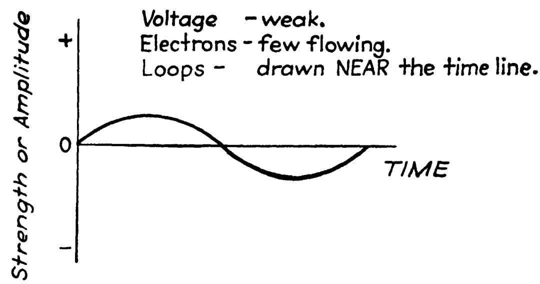


FIG. 92. This wave picture shows a weak voltage. It has a low amplitude.

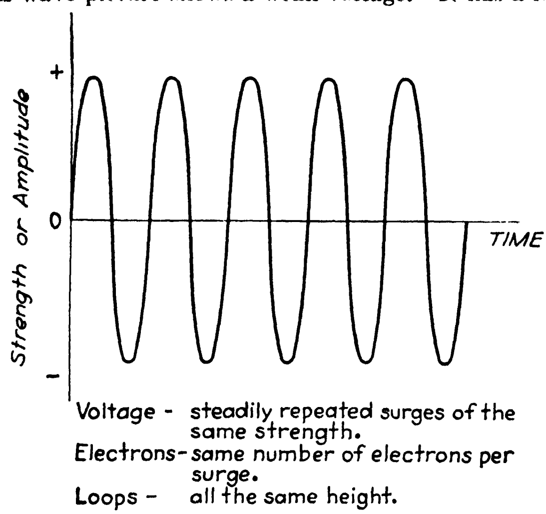


FIG. 93. A 60-cycle alternating voltage of an even amplitude.

as shown by the wave form. The rate will be 120 surges per second, or 60 round trips, or cycles, per second. You will notice that the amplitude of each surge is the same. Figure 93 shows the wave-form diagram for 60-cycle alternating voltage.

PART 5: HOW HIGH AND LOW FREQUENCIES ARE SHOWN ON THE OSCILLOSCOPE

The frequency of a wave can be shown by the circuit given in Fig. 94. The frequency is shown by the space between the loops

on the time line. (The time line shows on the plastic screen over the cathode-ray tube face.)

Experiment. Try this experiment to see how this is done.

Step 1. Connect a carbon microphone, a C battery, and an audio or microphone transformer, as shown in Fig. 94. Connect the secondary of the transformer to the vertical posts on the oscilloscope.

Step 2. Hum, whistle, or sound a sustained note into the microphone. Adjust the two gain controls until the wave is about $1\frac{1}{2}$ inches high and well spread on the time line.

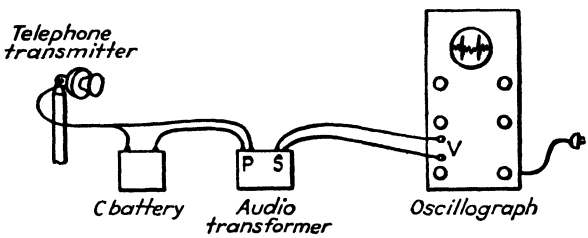


FIG. 94. How to show high and low frequencies.

Step 3. Whistle into the microphone, starting at a very low pitch and gradually increasing the pitch as high as you can. Watch the spacing of the loops along the time line.

Step 4. Repeat with the voice.

What is frequency? Now try a new thing with the wave-form picture. Slow up the time required for each surge, and see how this voltage picture will be drawn. If you keep the same space on the time line for each hundredth of a second and you use a voltage changing direction, or surging, at only 10 cycles per second, you will find that the loops are much flatter and the distance between the nodes much greater.

The frequency of an alternating current is the number of cycles, or electron round trips, that occur in 1 second.

Examine a low-frequency picture. The picture in Fig. 95 shows a voltage with a frequency of 10 cycles per second. Ten round trips, or cycles, have occurred in 1 second. One surge of voltage has taken only $\frac{1}{10}$ second. This is known as a *low-frequency* *'·nge.*

Examine a high-frequency picture. It is easy, then, to see that a voltage with a frequency of 20 cycles per second would be

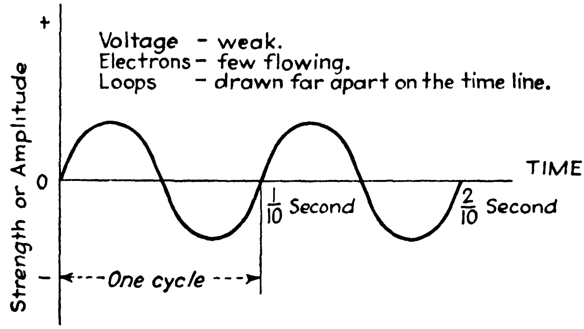


FIG. 95. Ten cycles a second; low frequency.

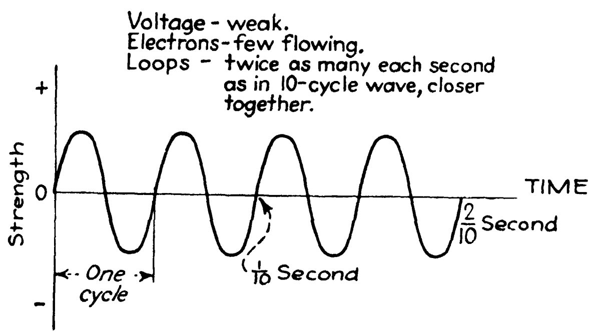


FIG. 96. Twenty cycles a second: higher frequency.

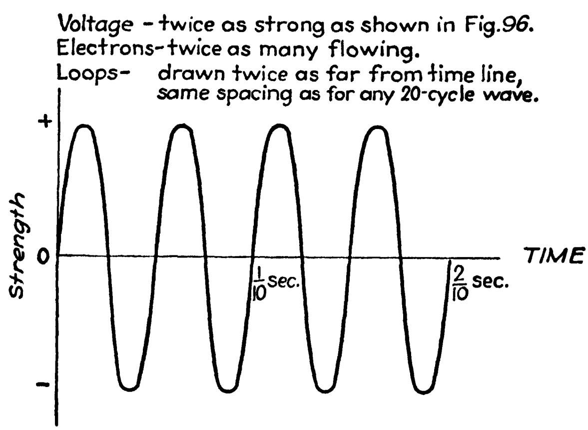


FIG. 97. Twenty cycles a second; higher frequency, stronger voltage.

drawn as in Fig. 96, in which you must bunch the cycles more closely together along the time line to show that many round trips occur each second. "High" as used here means fast—high rate of speed.

Frequency here does not affect the current or voltage strength. You may draw the loops either high or low, depending upon the strength of either high- or low-frequency voltages. A 20-cycle alternating current is shown in Fig. 96. This voltage has the same frequency as the voltage in Fig. 97, but the latter is stronger, as is shown by the higher amplitude of the loops above and below the time line. The current must build up and die out very quickly in high-frequency surges.

Questions

1. There are two wave pictures in Fig. 98. Which represents the stronger voltage?

2. Explain in terms of direction of electron flow the meaning of the terms *plus* and *minus* in an alternating current.

3. What is the frequency of the alternating current the power companies use for ordinary lighting and power circuits?

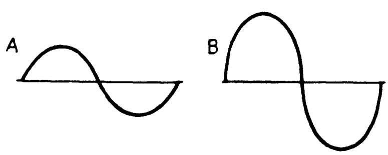


FIG. 98.

FIG. 99.

4. If this line _____- ____represents a wire in your house circuit, how many times per second do the electrons flow from left to right? How many times per second do they flow from right to left?

5. There are two wave pictures in Fig. 99. Which represents the higher frequency?

6. On what line is strength measured?

PART 6: HOW A PULSATING DIRECT CURRENT IS SHOWN ON THE OSCILLOSCOPE

Experiment. In this experiment you will examine a wave picture of a pulsating direct current.

Step 1. Set up the oscilloscope, and turn on the intensity control.

Step 2. Connect a tungar bulb to a storage battery, as shown in Fig. 100.

Step 3. Connect the test point to the V binding posts on the oscillograph.

Step 4. Connect a toy transformer to an alternating-current outlet.

Step 5. Attach the test points to the output of the toy transformer, set for 6 volts.

Step 6. Adjust the gain controls until the sine wave shows about 2 inches high. Attach the test points to the terminals of the battery which is being charged.

The sine curve you see when the test points are on the transformer terminals shows a 60-cycle alternating current. When you

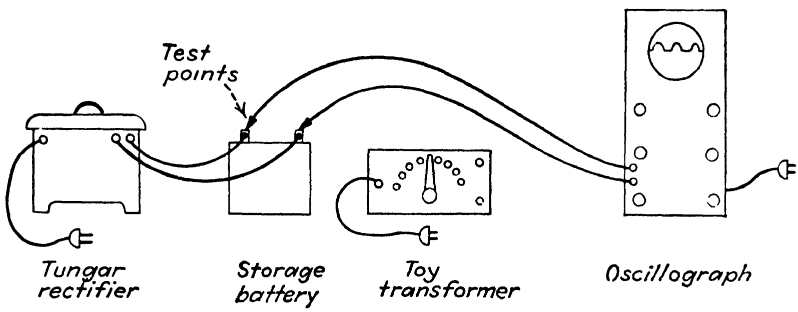


FIG. 100. Show pulsating direct current by connecting a tungar rectifier to the oscilloscope as shown here.

change the test points to the output of the tungar rectifier, half the current has been stopped by the rectifier tube, and you see remaining a pulsating direct current. By connecting the test points to the output of a receiving circuit across the phones or the primary of an audio transformer, you can see a pulsating direct-current voltage, which is in the form of an alternating current (called the *alternating-current component* of a direct current).

Inside of the oscillograph, a condenser is connected to the V binding post. This condenser charges and discharges with the pulsations of direct current, producing a sine wave on the screen which looks like an alternating current.

When you attach the test points to 6-volt battery, this condenser charges, and you see the green line jump sharply upward. Then it settles back to zero again when the charging current flow stops.

PART 7: HOW WAVE FORMS OF RECTIFIED ALTERNATING CURRENT ARE SHOWN

What is a pulsating direct current? All the wave-form pictures you have seen so far have been used to show the pulsations of alternating current, which flows in opposite directions in the wire. Now see if you can use the wave-form picture to show a direct current, in which the direction of electron flow does not change.

You will study the use of the vacuum-tube rectifier to change an alternating current to a current where the electrons move in separate, spaced surges along a wire, always moving in the same direction. This is called a *pulsating direct current.* Its wave shape

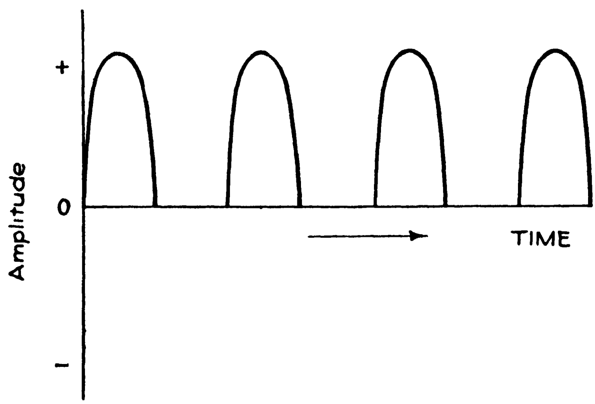


FIG. 101. This is the wave picture of a pulsating direct current.

is shown in Fig. 101. This wave is like an alternating-current picture showing only the loops above the time line. It is evident that the rectifier has cut off the current flow in the reverse direction, or the loops below the time line.

What is an alternating-current component of a direct current? In a direct current the electrons always flow in the same direction. The wave-form picture of the direct-current voltage flowing in a detector plate circuit is drawn as if it were an alternating current. That is, the sine wave that shows the increase and decrease of voltage strength is drawn above the time line, as was the pure direct-current wave picture.

It is possible to have a direct current that changes in strength at regular intervals. Its wave form is shown in Fig. 102. The direct-current surges are shown in the wave-form picture.

The whole curve form is drawn above the time line, since the current flow in this circuit is assumed to be in a positive direction. You know now that this is a direct current. You call this type of current flow the *alternating-current component* of a direct current.

What is pure direct current? Now you can readily understand what the wave picture of a pure direct current would be. Dry batteries, storage batteries, B batteries, and the filtered output from power packs deliver a current in which the strength remains the same and in which the flow is always in the same direction.

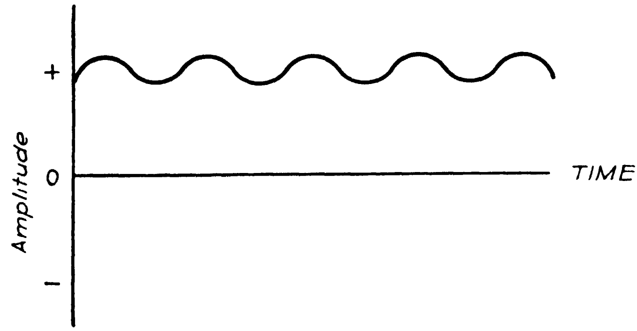


FIG. 102. A direct current with an alternating-current component.

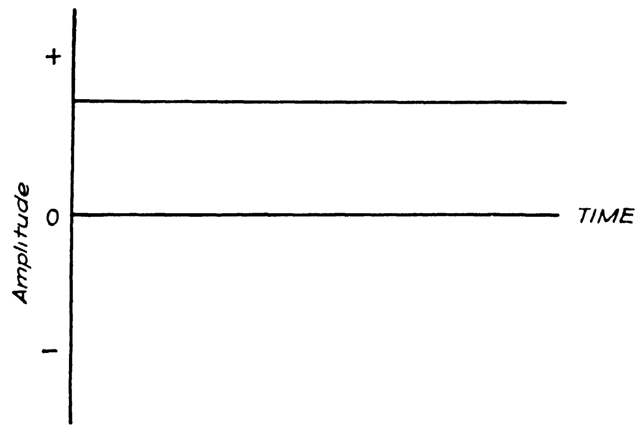


FIG. 103. A pure direct current.

The picture of a pure direct-current voltage is shown in Fig. 103, as a straight line that remains the same distance from the zero line.

Questions

1. Is the motion of electrons in one pulsation of a pulsating direct current any different from the motion of electrons in one pulsation of an alternating current?

2. Is anything happening in the wire between pulsations of a pulsating direct current?

3. State in your own words the meaning of the term "pulsating direct current." Does the electron flow in a pulsating direct current change direction?

4. Does the flow of electrons ever stop in a direct current which has an alternating-current component?

5. Is it ever correct to draw the alternating-current component so that the bottoms of the curves touch the time line? Try drawing it.

6. Does the quantity of electrons ever increase or decrease when a pure direct current is flowing through a wire?

7. Is it possible to picture a pure direct current either above or below the time line? Do you draw both a plus and a minus direct current above the time line?

8. Can the curve representing a pure direct current ever cross the time line?

Technical Terms

alternating-current component—A direct current in which the current strength increases and decreases, making the wave picture look something like that of an alternating current, although electrons flow in only one direction.

alternation—An electron surge in one direction; half of an alternating-current cycle.

amplitude—The strength of a current or voltage. Amplitude is shown by the distance of the loop above or below the time line.

audio transformer—A small transformer used to couple receiving detector and amplifier circuits or any two audio circuits.

current loops—The curved line which shows how the strength of the current surge grows and then dies away.

cycle—Two alternations, which make one complete round-trip electron surge.

frequency—The number of electron round trips that occur per second. The frequency of the house lighting current is 60 cycles per second.

intensity control—A control which increases or decreases the brilliance of the line on the oscilloscope screen.

kilocycle—A word meaning 1000 cycles.

meter—A distance equal to a little over a yard (about $39\frac{3}{8}$ inches). The length of radio waves is measured in meters.

negative loops—Loops drawn below the time line.

node point—The instant when there is no electron flow in the circuit. At this instant the line on the oscilloscope screen crosses the time line.

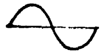
oscilloscope—An instrument that uses a cathode-ray tube to make visible the flow of electricity in circuits.

positive loops—Loops drawn above the time line.

pulsating direct current—A direct current flowing in one direction in regular pulses. Between pulses no current flows. A pulsating direct current may be thought of as half an alternating current, the other half having been stopped by a rectifier.

pulsation—The surge, or rush, of electrons in one direction during an alternation of an alternating current.

scope—An abbreviated expression, or slang term, meaning oscilloscope.

sine wave—A curve of the form  is known in mathematics as a sine curve.

60-cycle alternating current—An alternating current that changes direction 120 times per second, or has 60 cycles per second.

surge—A disturbance of the electrons in an atom. This disturbance affects nearby atoms. The effect, or surge, travels rapidly along a wire or other conductor. The electrons may move only a fraction of an inch, but at extremely high speed, while the surge travels along the wire at nearly the speed of light.

tungar bulb—A commercial form of gaseous tube used to rectify an alternating current for charging storage batteries.

wave-form picture—A diagram showing changes of direct- and alternating-current flow. A line used to show the action of the current.

CHAPTER 9

THE SIMPLEST RECEIVING SET—THE CRYSTAL DETECTOR

You now know enough about electricity and radio to make a simple receiving set. You will enjoy experimenting with actual radio equipment, operating it, and then learning the "whys" of its operation.

In the development of the radio industry in America, we owe much to radio amateurs, whose experiments carried out as a hobby helped to develop the radio art as we now know it. Some amateur experimenters worked blindly without knowing the "whys" of what they were doing. They had the knack for putting together different pieces of equipment and getting results. On the other hand, other experimenters, better trained and analytical in their thinking, looked for reasons for the various actions occurring in their tests. You will follow the latter practice in this book.

In this chapter you will assemble and try out several fundamental receiving circuits. You will learn how radio waves set up electrical currents in your receiving antenna and how these currents must be changed so that they can produce sound in your earphones. You will study the radio circuit called a *detector*, which changes the form of this current so that it will operate earphones and produce sound.

You will learn the following things in this chapter:

Part 1: How to Wire the Crystal-detector Circuit
Part 2: How to Operate the Crystal-detector Circuit
Part 3: Why the Crystal Detector Works

The new symbols introduced in this chapter are shown in Fig. 104.

PART 1: HOW TO WIRE THE CRYSTAL-DETECTOR CIRCUIT

What parts will you need? For this circuit you will need an antenna and a ground connection to receive energy from passing

radio waves, earphones to hear sound signals that the radio waves carry, and a detector.

How is the antenna made? Make the antenna of bare or insulated wire from 50 to 100 feet in length (see Fig. 105). You can use wire taken from a burned-out power transformer or from an

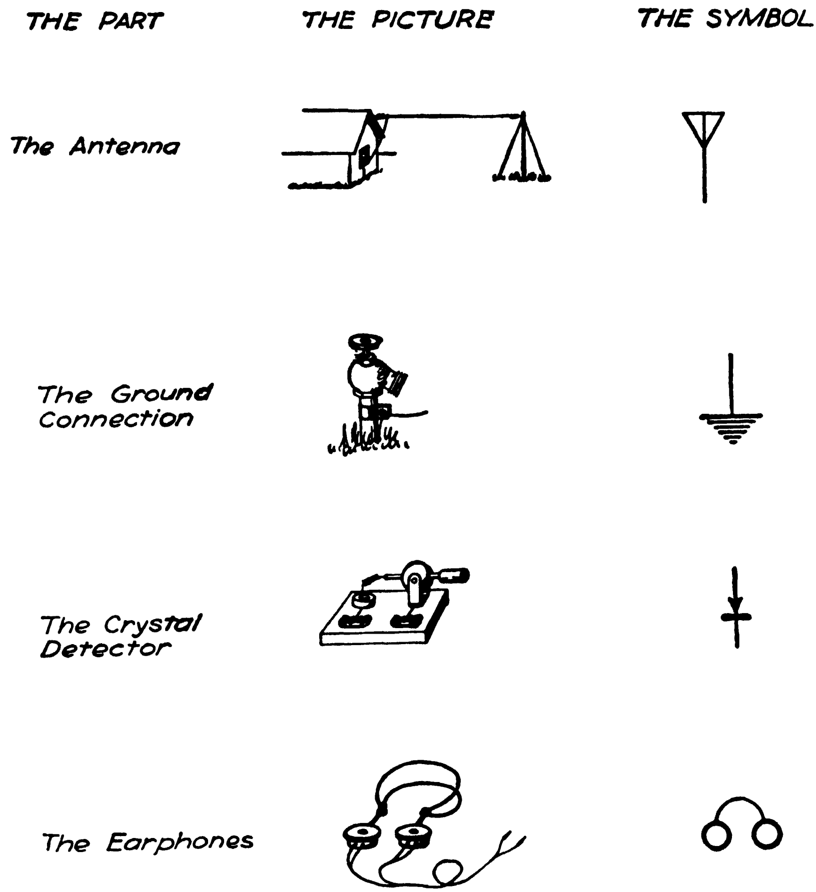


FIG. 104. These are the new symbols you will find in this chapter.

old receiving coil--the size of the wire makes little difference. You can make a makeshift antenna for your experiment by twisting one end of the wire around a nail driven into a nearby building or telephone pole, or by wrapping the end of the wire around a tree limb. Fasten a glass, or porcelain, insulator between one end of the wire and the tree to which it is fastened, and fasten another

between the other end of the wire and your house, near the window. Leave enough wire to reach the table on which your set is placed. The wire running into your room from the antenna is called the *leadin.*

A much better antenna is made of No. 14 enameled copper wire about 50 to 100 feet long and is placed at a height of 15 to 30 feet or more. The higher you can hang the antenna, the louder will be the music you hear in your earphones. A good antenna must

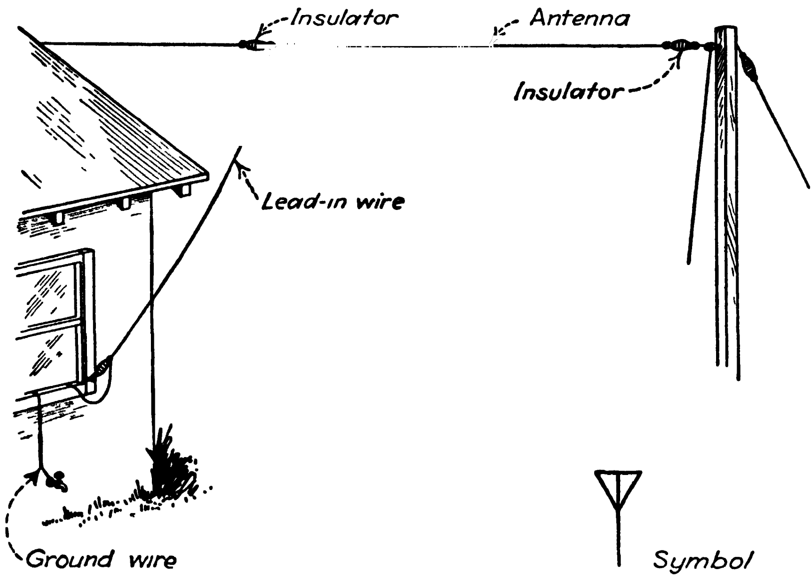


FIG. 105. Place the antenna so it is high and well away from trees or other objects such as buildings. Attach the ground wire to a water pipe as near the ground as possible. The leadin must be insulated all of the way to where it connects to the set. The ground wire need not be insulated.

be well insulated. The wire of the antenna and the leadin must come in contact only with the insulators until the leadin reaches your set (see Fig. 105). Use some kind of insulator, such as a porcelain tube, to keep the leadin from coming in contact with the house where it passes through to your set.

How is a ground connection made? Make a ground connection by attaching the ground wire from your set to a radiator, to a water pipe, or to a long metal rod driven into the ground. The wire running to the ground connection may be bare or insulated. You can purchase a ground clamp made especially for con-

necting the ground wire to a water pipe. Scrape the pipe clean and bright before attaching the wire or clamp.

How is a crystal detector made? For your first experiment you will use a crystal detector to make the music hearable. The galena or silicon crystal usually is mounted in an alloy placed in a small metal cup. You may also use a crystal diode detector.

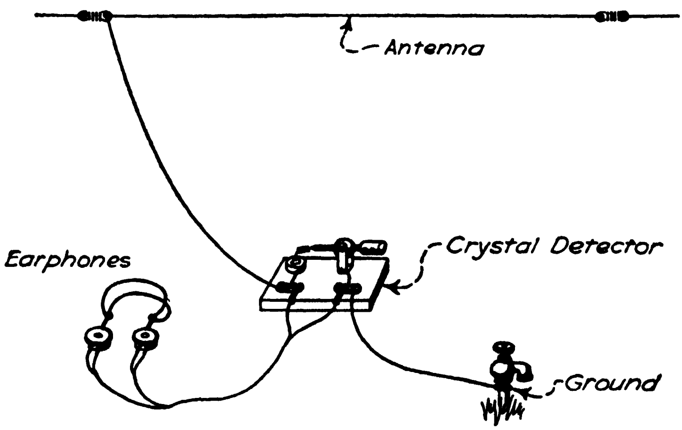


FIG. 106. This is the hookup of the crystal receiving set.

Caution. Do not attempt to solder a wire to the cup. The heat of a soldering iron will destroy the sensitivity of the crystal; even hot water may melt the alloy.

Fasten a piece of fine wire, called a *cat whisker*, on an adjustable arm, so that the point of the wire can touch the crystal lightly to find a sensitive spot.

Figure 106 shows a convenient way to mount the crystal detector for use in different experiments. Use two double Fahnestock clips, or binding posts, for making connections to the earphones, the antenna, and the ground.

What earphones should be used? For this experiment, use any good pair of earphones rated at 2000 ohms or more.

How to hook up the experiment. Attach the antenna (lead-in) wire to the outer side of one of the crystal-detector clips and the ground wire to the outer side of the other clip. Then attach the earphones to the inner sides of the clips, as shown in Fig. 106.

Compare the pictorial diagram with the schematic wiring diagram. Examine Figs. 106 and 107. Note that they are two dia-

grams of the same crystal receiving set. One is a pictorial diagram intended to show you how the board, or set, looks. You can use this diagram when you build the set. It shows where each part should be mounted on the board and where to place the connecting wires. The other is a simplified, or *schematic*, wiring diagram. In this diagram a *symbol*, which is a simplified or conventionalized drawing of a part, is used in place of the picture of the part.

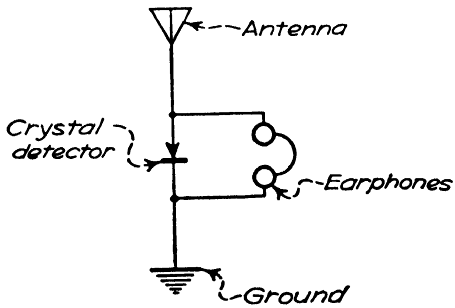


FIG. 107. The schematic wiring diagram for the crystal receiving set.

Note the symbols for the crystal detector, the earphones, the antenna, and the ground.

PART 2: HOW TO OPERATE THE CRYSTAL-DETECTOR CIRCUIT

Move the cat whisker lightly over the crystal surface until you find a sensitive spot, a spot where you find a station. You should hear a station with surprising clearness and intensity; generally, the music is much louder than you expect. If the music is weak or a station is hard to find, it may be because your fingers have touched the crystal. Your fingers leave on the crystal a film of grease that interferes with its operation. Wash off the grease with carbon tetrachloride or cleaning solvent, and your set should work.

Questions

1. Make a list of the parts you will need for a simple crystal-radio hookup.
2. What size of wire should you use for the antenna?
3. What is the "leadin"?
4. What effect has the height of the antenna upon the loudness of the sound in the earphones?

PART 3: WHY THE CRYSTAL DETECTOR WORKS

You can understand how this circuit changes the current in the antenna into sound in the earphones by following the electron flow

and surges through the wires of the circuit. Now study these operations by examining in turn each part of the set.

What happens in the antenna? Radio waves from the broadcasting transmitter station pass through your antenna and set up a flow of free electrons through the wire. At one instant the radio wave sets up an electron flow through the antenna wire toward the ground; at the next instant the wave causes the electrons to flow from the ground toward the antenna.

The radio waves reaching your antenna have the same frequency that they had when they left the antenna of the broadcasting transmitter station. If the frequency of the transmitter is 680 kilocycles per second (680,000 cycles per second) there were 680,000 electron flows into the antenna and 680,000 flows out of the antenna in every second. This causes 680,000 disturbances, which we call *radio waves*, to start out through space in each second. When these radio waves strike your antenna, they produce the same number of electron flows through your antenna toward the ground and the same number of flows from the ground toward the antenna. You know that an electron flow that changes direction is called an *alternating current*. The frequency of the alternating current in your antenna is the same as the carrier frequency of the broadcasting station to which you are listening. If you are hearing station KNBC of San Francisco, the frequency is 680 kilocycles per second. This statement means that the electron flow in KNBC's antenna occurs at the rate of 680 kilocycles, or 680,000 cycles, per second.

FIG. 108. You will hear nothing in the earphones with this connection.

The alternating current in your antenna has a wave form related to the wave form of the music that was played into the microphone at the transmitter station.

What are radio and audio frequencies? If you were to attach the earphones in the antenna-ground wire, as shown in Fig. 108, you would hear no music, because the *frequency*, or rate at which the electron flow changes direction, is so great that it will neither operate the earphones nor produce the sensation of sound in your ears. We say that this is a *radio-frequency current*, the name we give to currents that change direction more than 20,000 times per second.

The expression *audio frequency* is used to describe sound waves that produce vibrations that we can hear. Audio frequencies are hearable frequencies. But radio frequencies produce sound waves at a frequency too high for human hearing. Young persons with normal hearing can hear sounds with frequencies as high as 15,000 to 17,000 cycles per second. Older persons often find that they can no longer hear sounds with frequencies higher than about 12,000 to 15,000 cycles per second. While the highest frequency that can be heard is different for each person, the upper limit of audio frequency generally is taken to be 20,000 cycles. You will hear no sound when you connect the antenna and ground directly to the earphones, because the alternating current tries to set up in the earphones a vibration with a frequency of 680,000 cycles per second. You could hear no such sound even if it did exist.

You know now that the antenna current is unable to flow in the earphones or to produce sound in them. You will soon learn why this is so.

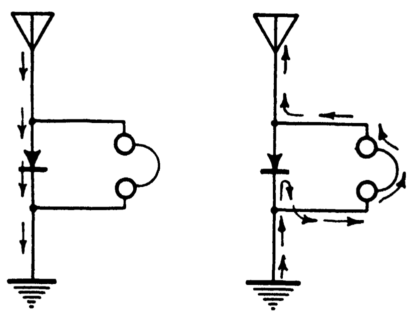


FIG. 109. Electron flow downward can pass easily through the crystal.

But what occurs when you connect a crystal detector in the circuit that makes it possible for you to hear in the earphones the music carried by the high-frequency (680,000-cycle) radio waves, since you know the earphones will operate only below 20,000 cycles?

The crystal makes the music audible. The job of the crystal is to assist to make the high frequency electron surges in the antenna circuit produce electron surges of audio frequency (less than 20,000 cycles per second) in the earphones by a kind of sorting-out process. The crystal can do this because it acts like a one-way valve. It will allow the electron flow to pass one way between the cat whisker and the crystal but will not allow the flow to pass the other way (see Fig. 109).

The result is that when the electron flow in the antenna is, let us say, downward, the electrons pass through the crystal to the ground, but when the flow is upward, the crystal stops the flow and forces the electron flow to pass through the earphones (see

Fig. 110). There are still 680,000 cycles of electron surges per second through the earphones, *but these surges are now all in the same direction.* They are a pulsating direct current, as shown in the wave picture, Fig. 111. No single radio-frequency surge lasts long enough to have a usable effect on the earphones, but as you will note from the wave picture, the radio-frequency surges come in groups. Suppose you examine an earphone to see how it works. You then can understand how these groups of electron surges can produce sound in the earphones.

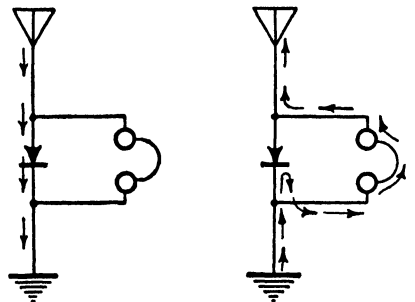


FIG. 110. But when the flow reverses few if any electrons can pass through the crystal. They are instead forced to flow through the coils of the earphones.

How do earphones work? The ordinary telephone receiver is one of the sensitive pieces of radio equipment by means of which you can hear slight changes in current strength as sound. Carefully unscrew the cap on an earphone and examine its construction. You find a small permanent horseshoe magnet with a coil

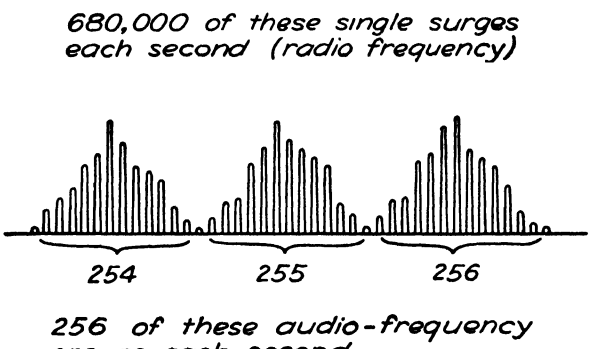
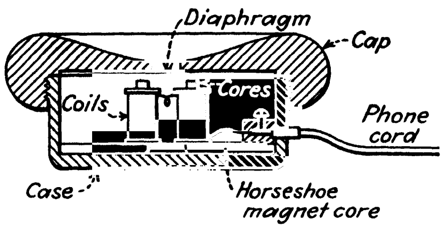


FIG. 111. This is the wave picture of a modulated, radio-frequency wave. Note that the radio-frequency surges come in groups. The groups were formed by the sound of middle C, 256 cycles a second, which was put into the microphone at the broadcasting studio.

of fine wire wound on each of its poles (see Fig. 112). A thin metal diaphragm, about $\frac{1}{1000}$ inch thick, is held between the receiver shell and the receiver cap, so that its center is very close

to the ends of the pole pieces. This permanent horseshoe magnet pulls the diaphragm, so that when the diaphragm is at rest, it is bent slightly toward the pole pieces (see Fig. 113). When electrons flow through the two coils, they become electromagnets and increase the pull of the permanent magnet. This added pull causes the diaphragm to move still closer to the pole pieces. When the current stops, the diaphragm is released and springs back to its original position. This slight motion of the diaphragm compresses the air in the space between it and the cap when the diaphragm moves upward and expands the air as it moves downward. The compression and expansion of the air is transmitted out through the hole in the cap and produces sound.



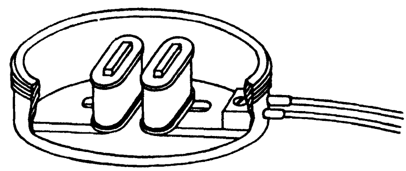


Fig. 112. The earphone consists of a shell, a cap, two coils or electromagnets wound on the ends of a permanent magnet, and a diaphragm of thin steel.

A steady current through the earphones merely pulls the diaphragm down and holds it in this position. You hear no sound except when the current stops or starts. But when the strength

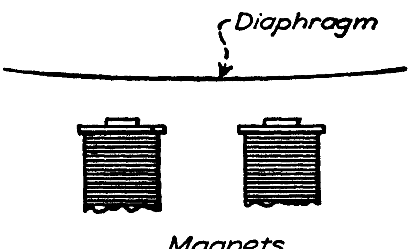


Fig. 113. When at rest, the diaphragm is under a slight pull from the permanent-magnet poles. You hear no sound when the diaphragm is at rest.

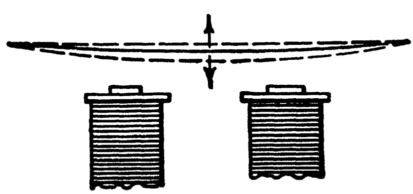


Fig. 114. The diaphragms move up and down as the strength of the current changes. This produces sound.

of the current changes, as it is constantly doing in the radio receiver, you hear sounds. The diaphragm then moves up and down as seen in Fig. 114.

How does pulsating direct current produce sound? When the alternating electron flow passes back and forth through the earphones between the antenna and ground in the circuit shown in Fig. 115, no sound is heard, because the motion produced by any

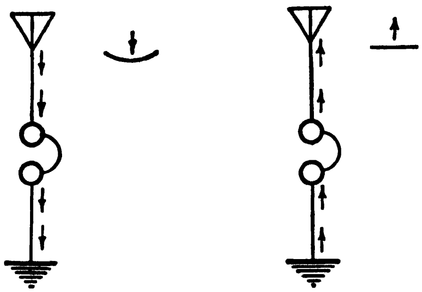


FIG. 115. Why a radio-frequency current produces no sound. One surge tries to move the diaphragm; but 1/680,000 second later, there is a pull in the opposite direction. The diaphragm is too heavy to move this fast so no motion occurs and you hear no sound.

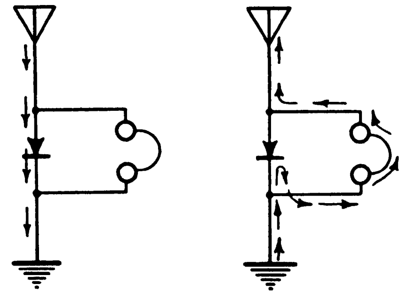


FIG. 116. This circuit will produce sound because the electrons now must flow only one way through the earphones. Now the pulls, all in the same direction, add together and move the diaphragm. As a result, you hear sound.

electron flow in one direction is immediately canceled when the electron flow surges in the opposite direction a millionth of a second later and sets up an opposing pull.

But the crystal circuit, Fig. 116, forces all the electrons to flow in one direction through the earphone coils and produces sound.

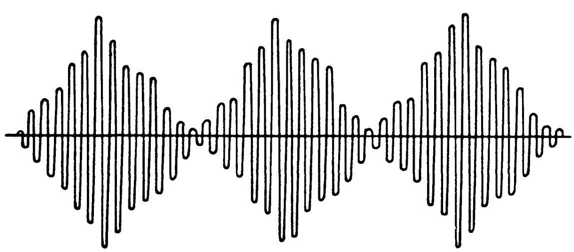


FIG. 117. This is the wave picture of a voice wave of 256 vibrations a second.

When an artist sings the note low C, his voice sets up 256 air vibrations per second. Figure 117 is a wave picture of the current flowing in the microphone as an artist sings into it. The current that flows in the antenna of the broadcasting station is the *modulated* radio-frequency carrier current, as shown in Fig. 118. Modulation changes the radio-frequency current strength to fit the

change in the strength of the currents produced by the singer's voice. Look at a magnified part of this modulated carrier wave shown in Fig. 118. Here you see that each current surge of the voice wave has altered the strength of the many radio-frequency surges to correspond with the changes in the strength of the voice wave. Other parts of the voice force these surges into a wave pattern whose outline looks like the original voice wave.

Now, when the many radio-frequency surges reach the earphone coils, they each set up a tiny bit of magnetism in the coils. The

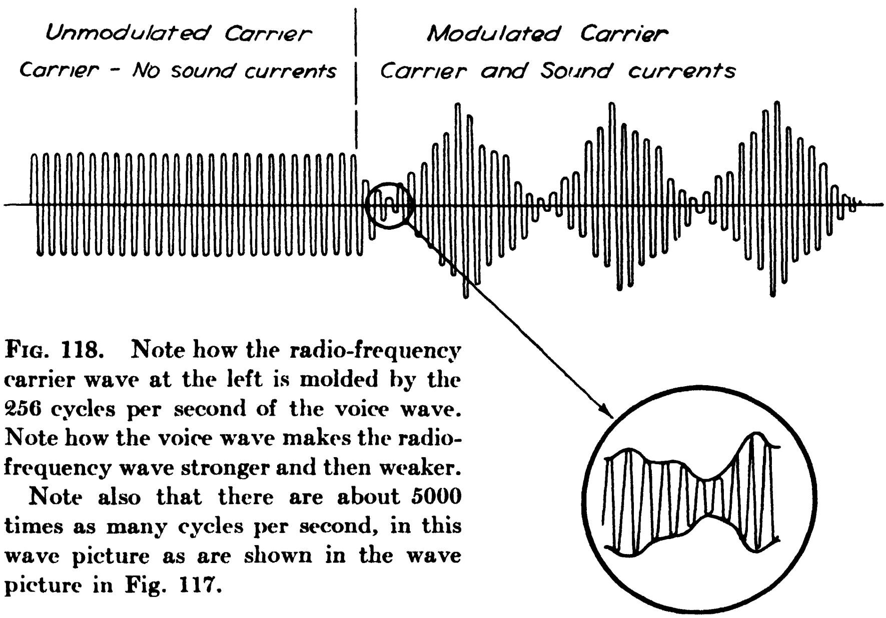


FIG. 118. Note how the radio-frequency carrier wave at the left is molded by the 256 cycles per second of the voice wave. Note how the voice wave makes the radio-frequency wave stronger and then weaker.

Note also that there are about 5000 times as many cycles per second, in this wave picture as are shown in the wave picture in Fig. 117.

resulting tiny pulls on the diaphragm come so fast that they blend together into a single strong pull that moves the metal diaphragm of the earphone. In this way the diaphragm follows the ups and downs of the shape of the voice wave. Its motion produces a sound similar to that which entered the microphone at the broadcasting studio, and you hear the artist's voice singing low C.

This process of sorting out the sound wave from its radio-frequency carrier is called *detection*, or *demodulation* (de-modulation).

What are the disadvantages of the crystal detector? During Marconi's early experiments, he tried many types of detectors, but all lacked dependability or were so insensitive that they failed to be commercially successful. You will recall that Fleming tried

out the two-element vacuum tube as a detector and found that it was little better than those then in use. In 1907 Pickard, an American engineer, developed the first crystal detector of the type you have just used in the preceding experiment. It proved to be sensitive electrically, but because its contact easily jarred off the sensitive spot of the crystal, it was not widely used in commercial radio.

DeForest discovered a more practical detector in 1906 when he sealed a bent wire grid into a vacuum tube. He thus created not only an excellent detector that would bring in radio signals but also an amplifier that would increase the strength of the signals.

Questions

1. What does *kilo* mean?
2. Why is it that you do not hear music when the earphones are connected between the antenna and ground wire?
3. What is a radio-frequency current?
4. Can you hear radio-frequency sound waves?
5. Can an alternating current flow with equal ease in both directions through the crystal and cat whisker?
6. Do the crystal and cat whisker change the radio-frequency current into a pulsating direct current or into an audio-frequency current?
7. Name the parts of an earphone.
8. Does an earphone contain a temporary or a permanent magnet?
9. What is detection?
10. Give several reasons why crystal sets are no longer popular.

Experiment 1: The Vacuum Tube Diode Detector

If you live near a powerful broadcasting station, you can substitute a Fleming valve-type diode for the crystal detector you have just tried. You may use the tube circuit board described in Chapter 6 and a triode vacuum tube connected so that it acts like a diode tube.

Note. A generalized pictorial drawing of a triode tube is used on the circuit board drawings because several different triodes may be used in these fundamental circuits. The 1LE3 triode is a good tube for student use.

How to Hook Up the Circuit

Step 1. Wire the tube circuit board as in Fig. 119.

Step 2. Connect the antenna to the plate of the tube and the ground to the filament (see Fig. 120).

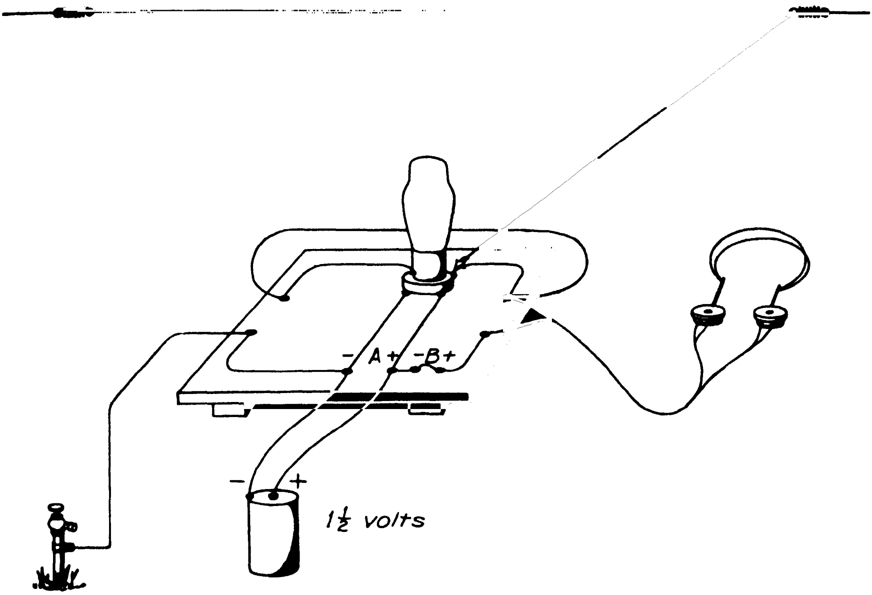


FIG. 119. The simple diode detector. Substitute the 1LE3 tube for the crystal detector. How does the loudness of the sound from this set compare with the sound from the crystal detector?

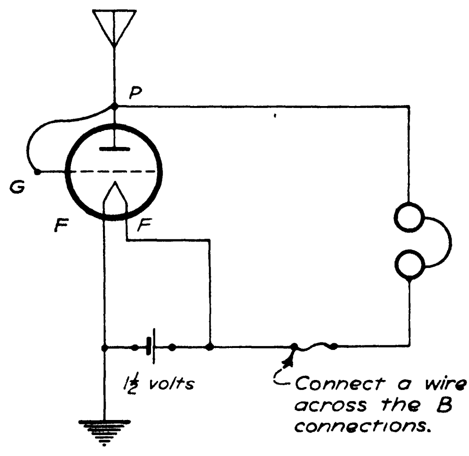


FIG. 120. This is the schematic circuit for the diode detector.

Step 3. Connect the tips of the earphone cord to the output connections on the set board.

Step 4. Connect a wire from the grid on the set board to the plate connection. This connects the grid and plate together so that they act as one element.

Step 5. Attach the correct A-battery size for the tube that you are using. If you have a 1LE3 tube, use a $1\frac{1}{2}$-volt dry cell for the A battery.

Step 6. Insert the tube in the socket.

Step 7. Connect a wire across the B-battery terminals. No B battery is used in this experiment.

How to Operate the Experiment

Now plug in the tube, put on the earphones, and you should hear a station.

Why It Works

Electrons flowing downward from the antenna reach the plate of the tube, but they cannot flow across the vacuum from the *cold* plate to the filament (see Fig. 121). Instead they flow through

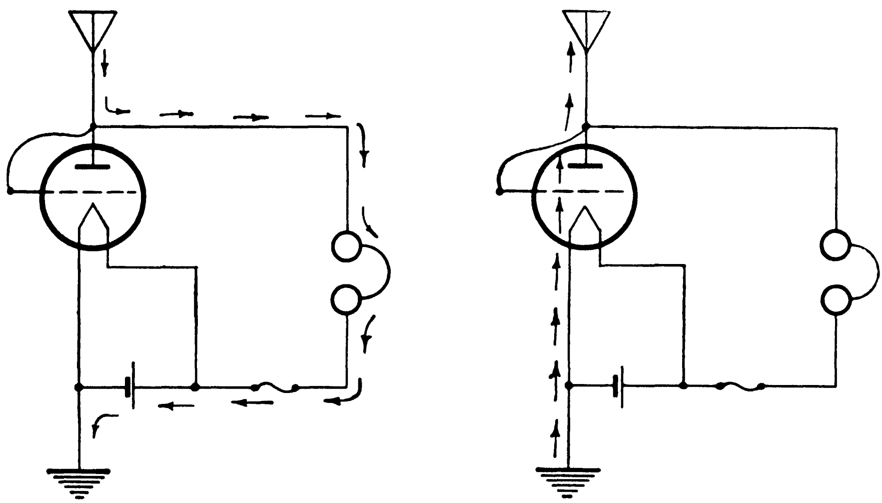


FIG. 121. Electron flow through the diode detector. Note how similar the action of this circuit is to that of the crystal detector.

the earphones and on to the ground. The next part of the radio wave draws the electrons *toward* the antenna. The electrons then flow easily from the filament, through the vacuum, to the plate, rather than through the high resistance of the earphones. Note that the diode tube has the same effect on the electron flow as has the crystal detector. It allows the electrons to flow in one direction through the detector and in the other direction forces them to flow through the earphones.

The vacuum-tube diode detector has one advantage. It will not jar out, as will the crystal detector. The volume of sound produced usually is not as great as that of a crystal. You can compare the two types of detectors for sensitivity by observing which gives the louder signals.

Experiment 2: The Three-element Vacuum Tube

This is a much better detector than the crystal or the diode because it combines the stability that the crystal detector lacks and the amplifying ability of the vacuum tube. With a triode detector, you should hear stations more clearly than with the diode tube, and you should hear stations that would be impossible to pick up on the crystal detector.

How to Hook Up the Circuit

Use the same tube circuit board and earphones that you used in the last experiment (see Figs. 122 and 123).

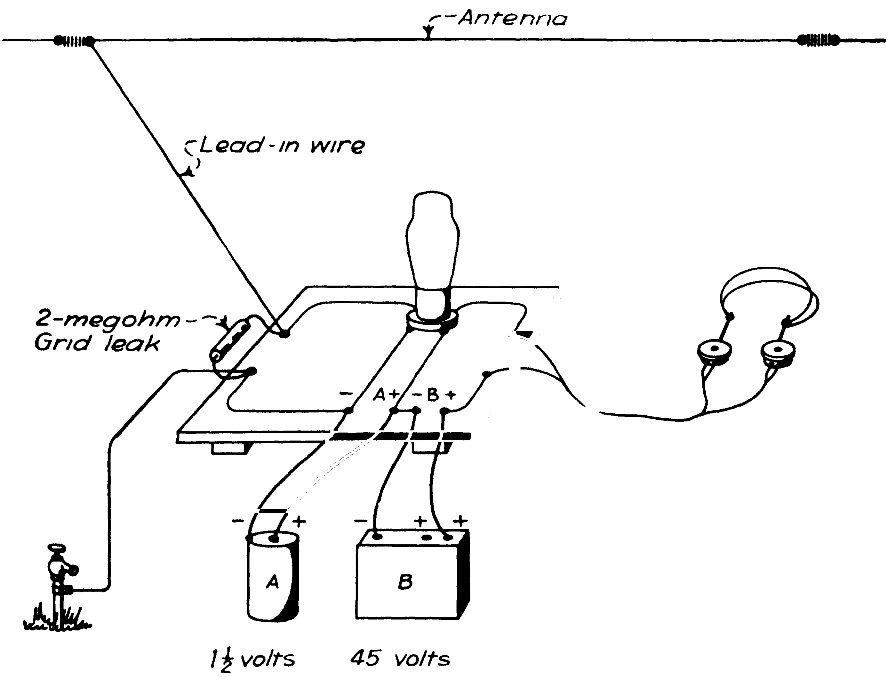


FIG. 122. Simple one-tube detector circuit. With this circuit you should hear louder signals because the tube is able to amplify the signals somewhat.

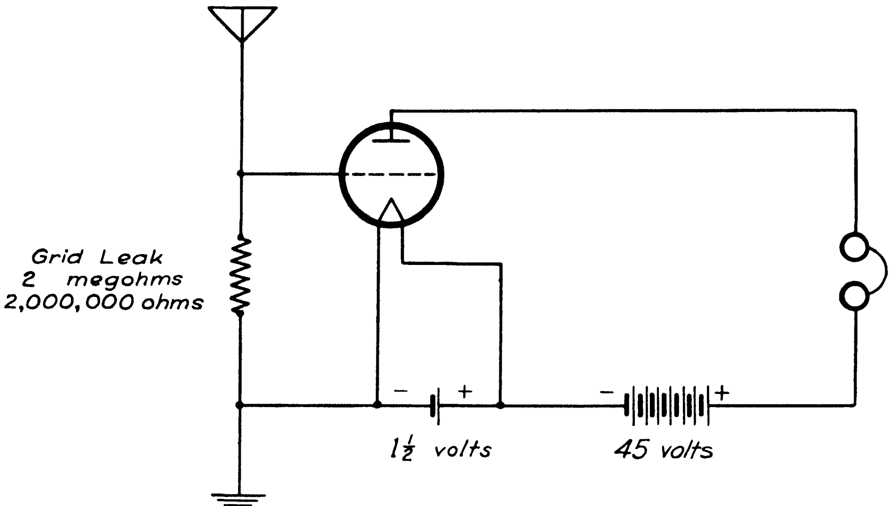


FIG. 123. Schematic circuit of the one-tube detector.

Step 1. Connect the antenna lead-in wire to the grid post on the set board. Connect the ground wire to the A-minus connection on the board (see Fig. 122).

Step 2. Connect the A battery, and test the filament to see that it will heat. Then connect the B battery to the proper terminals. Connect the wire from the positive side of the B battery to the B-plus terminal on the set board.

Step 3. Attach a pair of earphones to the output posts on the set board. If one of the earphone cords carries a colored stripe, or tracer, connect this wire to the board terminal that leads to the positive side of the B battery. This will prevent the earphones from being demagnetized.

Step 4. Connect a small fixed grid-leak resistor of 2 megohms (2 million ohms resistance) on the tube board between the antenna and ground connections.

How to Operate the Experiment

Heat the filament by attaching the battery wires. This puts the set in operation, and you should hear a station.

Why It Works

Before you connect the antenna, you hear no sound in the earphones. Why is this? The hot filament is surrounded by elec-

trons in the space charge. Electrons are attracted to the positive plate and a steady plate current flows through the earphones. No sound is heard because the current flowing through the earphones is steady.

A signal from the antenna produces sound. However, when you attach the antenna to the grid, you hear sound in the ear-

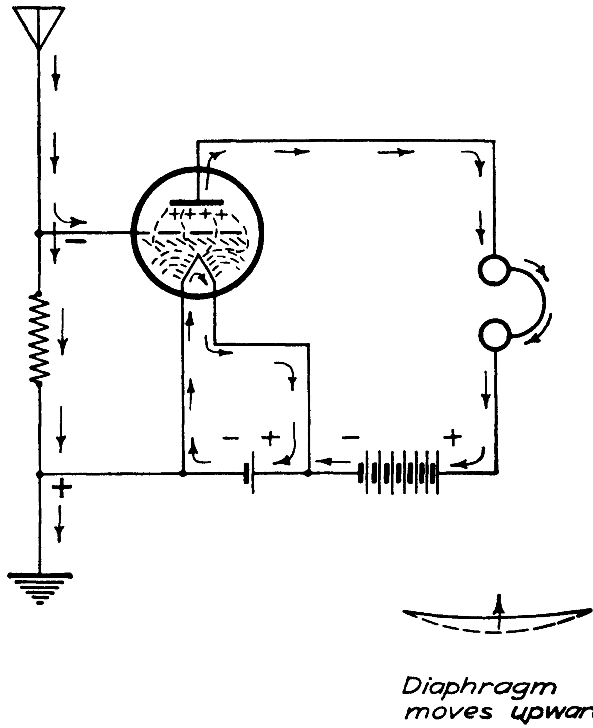


FIG. 124. When electrons flow on the grid, they repel electrons in the space charge and few reach the plate. There is little motion of the earphone diaphragm. It moves upward because the plate current flowing through the coils is reduced.

phones. When the electrons flow *from the antenna* toward the ground, the resistance of the grid leak forces some of them onto the grid, and they make the grid negative. The negative grid repels the electrons in the space charge and allows fewer electrons to reach the plate, so that the plate current is weakened (see Fig. 124).

When the current flowing from the plate through the earphones becomes weaker, the diaphragm of the earphones moves away from the magnet and you hear a sound.

When the electron flow moves *toward the antenna*, the free electrons are drawn from the grid, which becomes less negative (see Fig. 125). The positive grid attracts the electrons in the space charge. As these electrons move toward the grid, some are captured by the tiny area of the grid wires, but most of them go on past the grid, to the plate, and on through the earphones. The current flow through the earphones is then stronger than it was

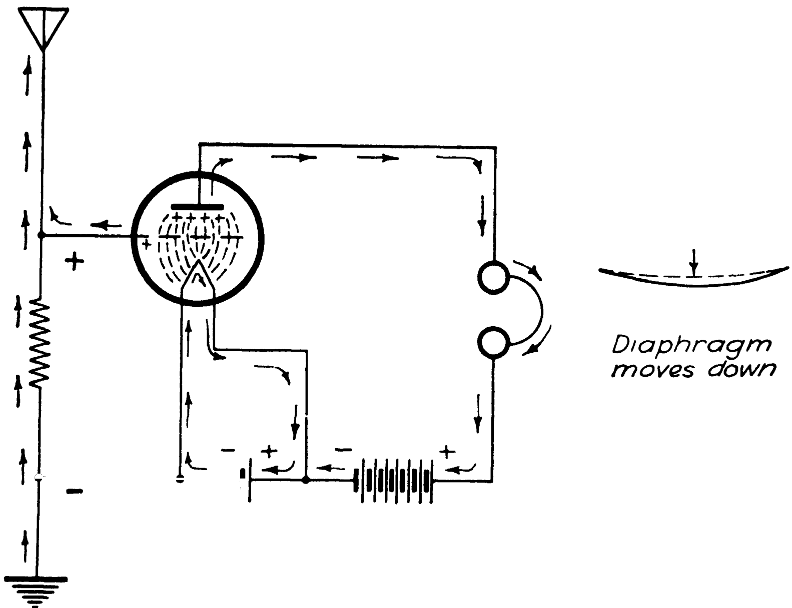


Fig. 125. When the electrons are pulled off the grid, it becomes positive and attracts electrons from the space charge. Result—more electrons flow through the tube, there is greater pull on the diaphragms, they move downward, and you hear sound.

when there was no signal coming in. This increase in current pulls the diaphragm of the earphones farther downward, again producing a sound.

Why is the music louder? The English have long called the vacuum tube a vacuum *valve*. You might think of it as an extremely sensitive electron valve, or faucet. Then think of the grid as the handle that controls the flow of current through the tube, or valve. Think of the B battery as the powerful pump forcing the electric current to flow through the plate circuit from

pump to the filament, across the vacuum to the plate, through the earphones, and back to the B battery.

Now, when groups of the infinitely tiny electrical charges, or electrons, reach the handle (the grid), they can weaken this powerful current flowing through the tube. That is, when the grid is negative it prevents the plate from pulling electrons across the grid. But, unlike the valve, when the grid is positive it *helps* the plate pull electrons across the vacuum; it not only allows the plate current to become stronger, but it can also increase the strength of the plate current. This is the way a few electrons on the grid control a huge quantity of electrons flowing through the plate circuit. The tube not only detects, or makes audible, the signals, but it also amplifies at the same time. This will be explained in detail in a later chapter.

You hear the sounds in the earphones because these few electrons on the grid cause large changes in the plate current.

Questions

1. Explain how a Fleming valve works.
2. What does *diode* mean?
3. What does *triode* mean?
4. Describe the effect of the grid on the plate current.
5. Why are radio tubes often called *vacuum valves?*

Technical Terms

antenna—A wire supported above the ground, insulated from its supports and from the ground throughout its entire length. The antenna is connected to the receiving apparatus by a lead-in wire. The antenna is sometimes called the *aerial.*

audio frequency—Waves with a frequency below 20,000 cycles per second, which can be heard.

cat whisker—A piece of fine wire which is fastened on an adjustable arm so that the end of the wire can be touched lightly against the crystal.

crystal detector—A crystal, such as galena or silicon, on which a fine wire makes a light contact. The crystal detector will allow electricity to flow in only one direction through it.

demodulation—The process of separating radio-frequency and audio-frequency voltages in a detector circuit. It is also called *detection.*

detection—See *demodulation.*

diode tube—A vacuum tube which contains just a plate and a filament.

ground connection—The place where the ground wire is attached to a water pipe or to permanently moist earth.

leadin—The wire connecting the antenna to your receiving set.

radio-frequency waves—Waves with a frequency above 20,000 cycles per second, which alternate too fast to be heard by the human ear.

space charge—The electron cloud which surrounds the heated filament, or cathode, of a vacuum tube.

CHAPTER 10

ALTERNATING CURRENTS IN RADIO CIRCUITS

It is necessary to return to the study of electricity for you to understand *tuning*, which is the process of selecting stations. You will have to learn how alternating currents act as they surge through tuning circuits. You will also need to find out more about how alternating currents affect the vacuum tube.

When you examine circuits used for tuning, you will discover that they have two new important parts: the coil and the condenser. You will learn something of what occurs in a coil or a condenser when direct and alternating currents flow into or through them.

You will learn the following things in this chapter:

Part 1: How Coils Are Constructed and Used
Part 2: How a Voltage Can Be Induced in a Coil
Part 3: How Condensers Are Constructed and Used
Part 4: How Choke Coils Work—Inductance
Part 5: What Reactance Is and How It Is Found
Part 6: How Back Voltage Occurs in a Condenser
Part 7: How Impedance—Alternating-current Resistance—Is Worked Out

New symbols found in this chapter are shown in Fig. 126.

Ohm's law for alternating currents can be highly complex, but you will study only its simpler forms, which will give you an understanding of its application to radio circuits.

Now examine the coils and condensers in the radio circuits. Learn how they are made, the theory of their operation, and how the alternating-current version of Ohm's law applies to them.

PART 1: HOW COILS ARE CONSTRUCTED AND USED

Examine a radio coil. Tear the coils out of at least one old radio receiving set and, if possible, out of two or three. You will

find these coils to be rather simple in construction. Coils in modern receiving sets are apt to be much more compact and are wound with finer wire. Note also the different materials that are used for the coil form.

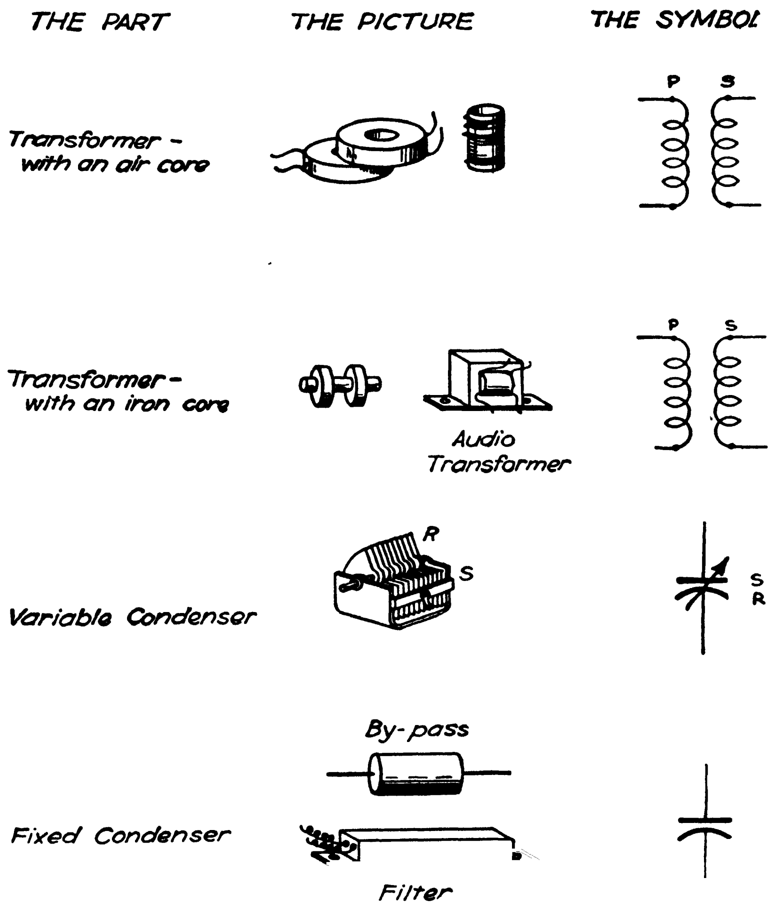


FIG. 126. These are the new symbols that you will find in this chapter.

If you have several of these coils, tear one apart to see how it is constructed. Note how it is wound and how the wire is fastened to the form. Measure the size of the wire with calipers or with a wire gage. When two separate windings, or coils, are wound on the one form with no connection between them, the resulting coil is called a *transformer*.

When you examine the part of the circuit connected to the

transformer, shown in Fig. 127, you find that the smaller coil is connected to the antenna and to the ground and the larger coil is connected to a variable condenser and to the tube.

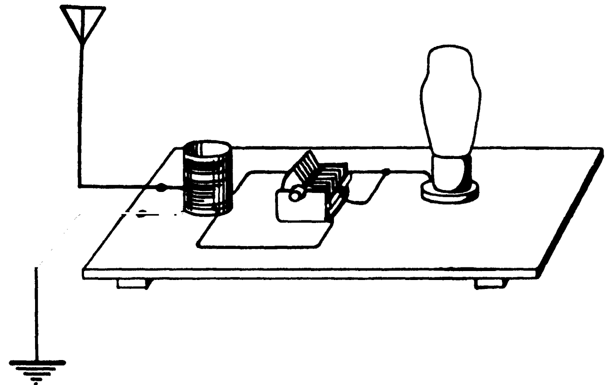


FIG. 127. How the radio coil is connected in one radio circuit.

The schematic circuit diagram in Fig. 128 shows clearly that there is no connection between the two separate windings of the transformer.

In this new type of circuit, in which there is no connection between antenna, ground, and tube, there must be some way for

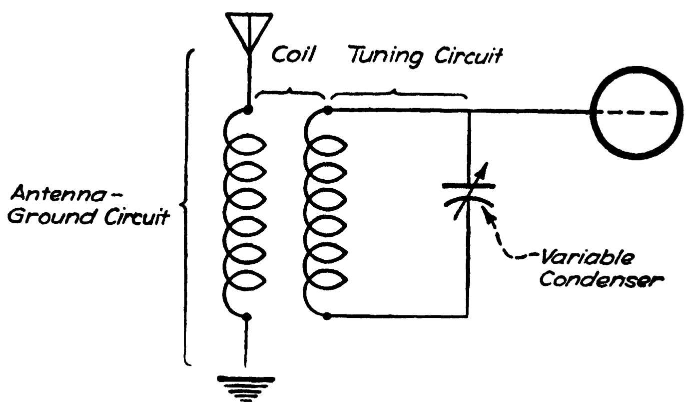


FIG. 128. The schematic circuit diagram of the connections to the radio coil shown in Fig. 127.

the electricity in the antenna-ground part of the circuit to affect the second winding, or coil.

A current actually does flow in the larger coil when a current flows in the antenna circuit, but this current is not the same as

the one in the smaller coil. The process by which a current flowing in one coil sets up, or produces, a voltage in another nearby coil is called *induction*.

PART 2: HOW A VOLTAGE CAN BE INDUCED IN A COIL

Experiment: Induction by a Moving Magnet

There are several ways to produce a voltage in a coil of wire. Even though each appears to be a different process, they all work on the same principle. Probably the simplest way to induce a voltage in a coil is by moving a magnet in and out of the coil. The voltage induced in the coil drives a current of electrons through the wires. Try it.

Hookup and Operation

Step 1. Connect the ends of a coil consisting of about 50 turns of fine insulated magnet wire to a 50-0-50 direct-current microvoltmeter (see Fig. 129).

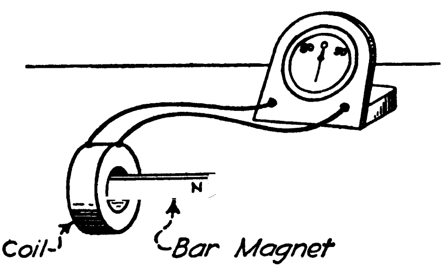


FIG. 129. One form of induction. A current is induced in the coil only when the bar magnet is moved.

Step 2. Hold the end of a magnet inside the coil. A bar magnet or a horseshoe magnet of the type used in physics laboratories is recommended. Do not move the magnet. Does the meter hand move when the magnet is still?

Step 3. Now move the magnet *slowly* INTO the coil. In which direction does the meter hand move?

Step 4. Now move the magnet *slowly* OUT OF the coil. Does the meter hand move in the same direction as before?

Why It Works

This simple experiment shows how a voltage can be induced, or generated, in a coil.

When you hold the magnet motionless in the coil, you notice no motion of the meter hand. But when you *move* the magnet, the meter hand does move. Glance again at Fig. 20, which shows the shape of the field of force around the ends of a bar magnet.

Fact 1. A voltage is generated only when the magnetic field is in motion.

When you move the bar *into* the coil, its magnetic field penetrates the copper wire and sets up a voltage which causes the free electrons to flow through the wire and a current of electrons to flow to the meter. The meter hand moves in one direction.

Fact 2. A magnet moved inside of a coil of wire generates a voltage that causes an electron flow, or current of electricity, in the coil of wire and the circuit.

Fact 3. When you move the magnet out of the coil, the electron flow changes direction.

The meter hand moves in the opposite direction when you pull the magnet out of the coil.

Now move the magnet in and out of the coil, slowly at first, and then rapidly. Note how far the meter hand swings as you move the magnet slowly; then watch the amount of its swing as the magnet is moved rapidly.

Fact 4. The faster you move the magnet, the larger the voltage induced in the coil and the stronger the current in the circuit.

You have now learned four new facts, or principles, which will be of great importance to you as you study alternating current and the radio circuit.

Rule. A voltage is induced in a coil of wire only when the field of magnetic force around the wire is moving, that is, becoming stronger or weaker.

Experiment: Induction between Two Coils

You can substitute a coil magnet (an electromagnet) for the permanent magnet and again induce a voltage in the coil.

For convenience, we call the coil through which the current first flows the *primary* and the coil in which the voltage is induced the *secondary*. As you have learned, the two coils together are called a *transformer*.

Method 1

You can induce a voltage in the secondary coil when the current flowing in the primary coil is steady.

Hookup and Operation

Step 1. Wind a primary and a secondary coil, each with about 100 turns of No. 18 enameled copper wire. Fasten one wire from

the primary coil to the dry cell, but keep the other wire unattached for the present. Connect the secondary coil to the meter. (See Fig. 130 for an illustration of these connections.)

Step 2. Now *hold* the unattached wire on the other terminal of the dry cell, and move the primary coil up and down over the secondary coil. Watch the meter.

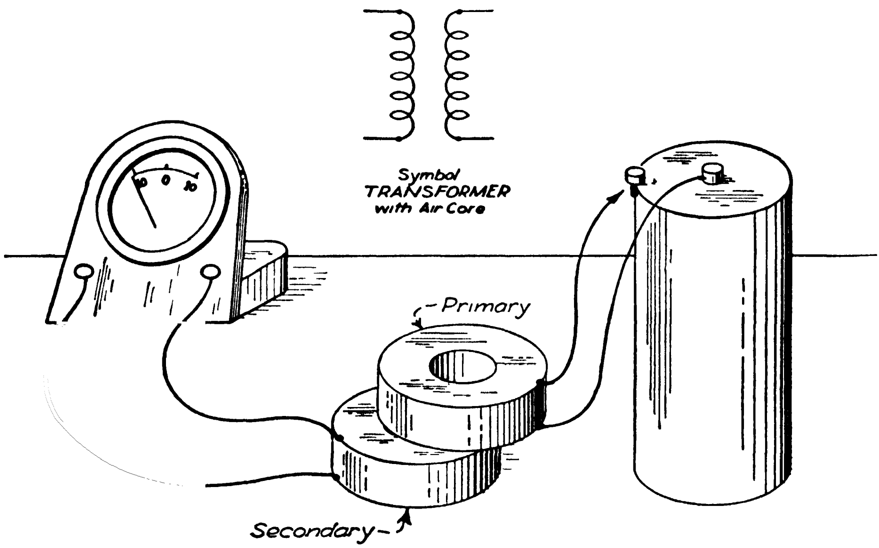


Fig. 130. Another form of induction. You can substitute an electromagnet for the permanent bar magnet in Fig. 129 and induce a current in the secondary coil. Try it and watch the meter.

Caution. Leave the current on for only a few seconds. The dry cell quickly runs down, and the wire becomes hot if the current remains on too long.

Why It Works

When you move the primary coil up and down over the secondary coil, the meter hand acts as it did when you moved the bar magnet in and out of the coil. In other words, the effect is the same when you move the coil as when you moved the magnet.

The magnetism around the wires of the secondary coil is strong when the primary coil is close and is weak when the coil is moved away. The changing magnetic field induces a voltage in the secondary coil. If the coil is a closed circuit, a current will flow.

Rule. A voltage is induced in a coil and a current flows in the circuit when the magnetic field around it becomes stronger or weaker.

Method 2

You can also induce a voltage in the secondary *without moving either coil.*

Hookup and Operation

Step 1. Use the coils that you used in the last experiment. Lay the two coils together. Connect them as shown in Fig. 130.

Step 2. Touch the unattached wire from the primary coil to the other terminal of the dry cell. Then take it away. Note that the meter hand kicks and then remains still.

Rule. A voltage is induced in the secondary coil when you make and break the primary circuit.

Why It Works

You saw when you used the bar magnet that a voltage was induced in the secondary coil only when the magnetic field around its wires was getting stronger or weaker. Now you see a voltage induced in the coil when you either make or break a connection.

Voltage is induced when you make a connection, because the current that flows through the wires of the primary coil when the wires are touched to the dry cell rapidly increases to full strength. As the current grows stronger, it forms around the coil a magnetic field that grows in strength with the current. You remember that the strength of the magnetic field depends on the strength of the current in the coil (see Chapter 4).

So a voltage is induced in the secondary when you make a connection, because the growing current creates a magnetic field of growing, or changing, strength. You also find that a voltage is induced at the break of the circuit.

Experiment: Induction between Two Coils with Alternating Current in the Primary

This experiment shows a more practical way to induce a voltage in the secondary coil. In practice you will find many methods of inducing voltages but the one most commonly used is that of inducing a voltage in a secondary coil when an alternating current flows in a primary coil.

Hookup and Operation

Step 1. Connect the primary coil to the terminals of a small step-down toy transformer, and plug the transformer into a wall socket. An alternating current will now flow through the primary coil (see Fig. 131).

Step 2. Connect a 6-volt automobile head lamp to the secondary coil.

Step 3. Lay the primary coil on the secondary coil connected to the lamp. Adjust the voltage of the toy transformer until the

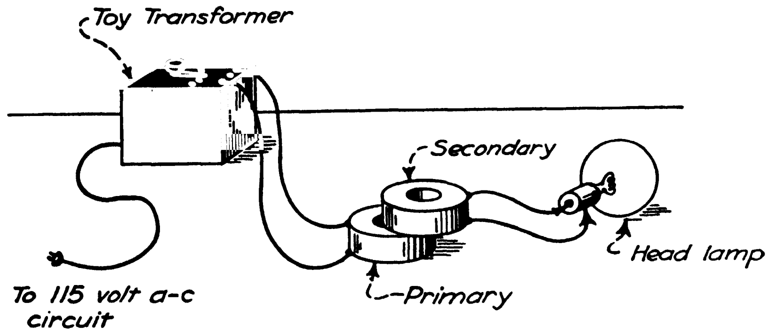


FIG. 131. Induction using an alternating current. An alternating current in the primary coil will induce a voltage in the secondary. This is the commonly used method of induction.

lamp glows. Note that the lamp lights even though the two coils do not move.

Why It Works

This experiment shows that an alternating voltage is induced in the secondary coil when an *alternating current* flows in the primary. This is called *mutual induction,* or the setting up of a voltage in a secondary circuit when a current flows in the primary, even though neither coil is connected to the other.

When you studied wave-form pictures, you learned that the strength of the alternating current was always changing. The sine-wave picture showed that both the voltage and the current increased and decreased at a regular rate. In your last experiment the alternating current flowing through the primary coil set up a magnetic field around it. The strength of this field changed as the strength of the current changed. The secondary coil was close enough to the primary so that this same magnetic field pene-

trated the secondary coil. The wires of the secondary were in a magnetic field of changing strength, and so a voltage of changing strength was induced in this coil.

In this setup you do not have to move the primary coil or make and break the current in the primary. A voltage is induced in the secondary coil because the magnetic field around it is constantly changing in strength.

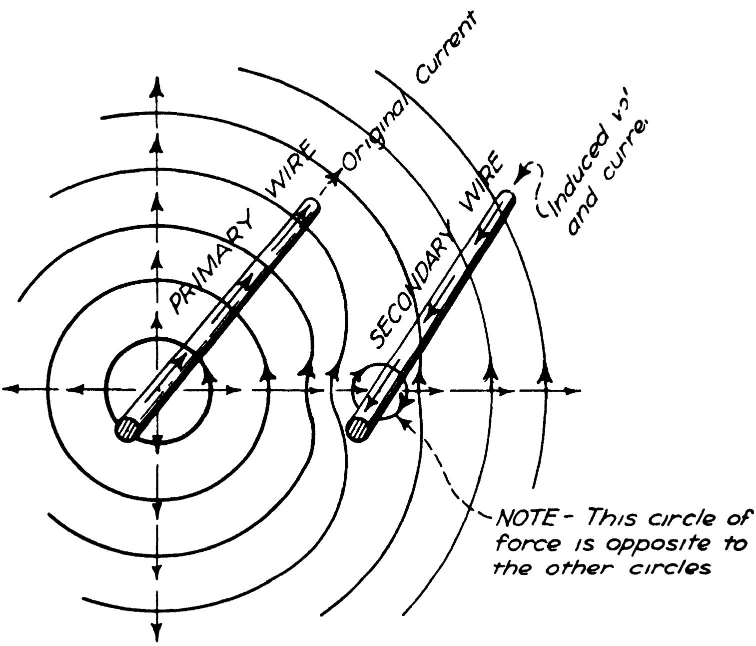


FIG. 132. The action of the lines of force are opposite in direction around the secondary wire so the induced voltage is in the opposite direction to the original current in the primary wire.

In what direction does the secondary current flow? It is important to know which way the induced voltage causes the current in the secondary circuit to flow. At the instant when the current starts to increase in the wires of the primary coil, the magnetic field spreads outward around the primary wires.

As the magnetic field of the primary coil spreads outward, the lines of force cut across the wires of the secondary coil, as shown in Fig. 132. The energy in the magnetic field causes the free electrons in the secondary wire to flow. Hold your left hand on the secondary wire, with your fingers pointing in the direction of the

small circle of force. You can then find the direction in which these electrons move by using the left-hand rule. Note that the small circle of force collapsing on the secondary wire is moving *inward toward the wire.* It is moving in the opposite direction to that of the field around the primary wire, which is moving *away from the wire.* Consequently, this collapsing line induces a voltage in the secondary wire in the opposite direction to that of the current in the primary.

Rule. The voltage induced in the secondary is in the opposite direction to the current in the primary.

How can the strength of the induced voltage be increased? There are several ways to make the induced voltage in the secondary wire stronger. One way is to place the handle of a pair of pliers or a piece of iron through the center of the two coils. Use a 12-volt lamp. The piece of iron, placed inside the coils, is called a *core.*

Why it works. As more magnetism from the primary coil reaches the secondary coil, a greater number of electrons flow through the secondary coil to the right. If the magnetism had to pass through air only to the secondary coil, the magnetic field around the secondary would be weak. Iron is a very much better pathway for magnetism than air. So when you put a piece of iron inside the coils, the iron carries the magnetism readily to the secondary coil. As a result, the field around the secondary coil is much stronger than before and a much stronger voltage is induced in the secondary. You now have an *iron-core transformer.* You will study more about this type of transformer in the chapters "Basic Receiving Circuits Using Alternating-current Tubes" and "Power Supplies."

What practical uses are made of induction? You may not have realized that when you moved a magnet through a coil of wire, you had a simple generator of the type that furnishes light and power to your home. In the generator many coils are set in a magnetized frame and other coils are whirled past them. A voltage is induced in the coils as they whirl through the fields of the magnets.

In the magneto of the outboard motor which drives your boat, large permanent magnets set in the flywheel whirl past coils and generate the voltage that gives you the spark at the spark plug.

In your car there is an induction coil that gives you the spark to make the engine run. Contact points in the coil primary circuit make and break the circuit from the storage battery to create the changing field around the primary coil. This induces a high voltage in the secondary, which produces the spark for the spark plugs.

These are but a few practical examples of the uses of induction. You will discover many more in your study of radio circuits.

Questions

1. What is a transformer?
2. What is induction?
3. State several ways in which you can induce a voltage.
4. Can a stationary magnetic field induce a voltage in a nearby coil?
5. How can you recognize the primary coil in a transformer?
6. Can a steady direct current flowing in a primary coil of a transformer induce a voltage in the secondary?
7. What is meant by "mutual inductance"?
8. Is the induced voltage in the same direction as the original current?
9. Give several ways of increasing the strength of the induced voltage.

PART 3: HOW CONDENSERS ARE CONSTRUCTED AND USED

Examine the condenser. The next instrument you will find in radio circuits is the variable condenser shown in Fig. 133.

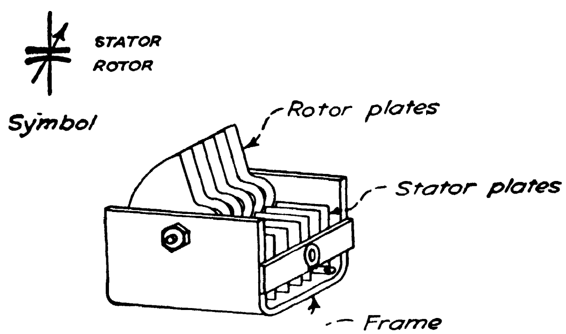


FIG. 133. This is the variable condenser you use to tune your radio receiver to a station you wish to hear.

Examine one of these condensers carefully, and see how simple it is. The fixed metal plates mounted in a U-shaped frame are called the *stator*, or *stationary, plates*. When you turn the knob, another set of plates moves between the stationary plates. These plates are called the *rotor plates*. Note that the rotor and stator

plates do not touch each other; they are separated from each other by insulators.

Here you have a mystery: If the two sets of plates do not touch each other, how can electrical energy be transferred from one set of plates to the other? You will know the answer to this question when you learn what a condenser is and how it works.

What is a condenser? Look at the wiring of a radio set. You find it contains one or more variable condensers that are used to tune the set. You will also find many small fixed condensers. The capacity of a fixed condenser is not adjustable as is that of the variable condenser. Fixed condensers are built in several shapes, some in rectangular cartons, some flat, and some round (see Fig. 126).

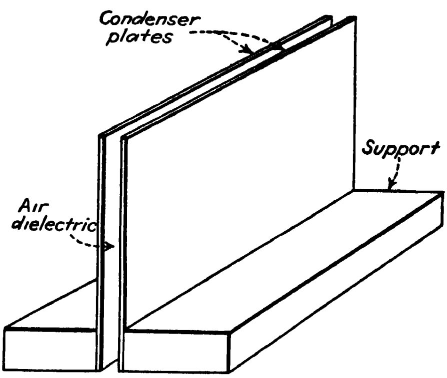


FIG. 134. This is a simple form of condenser. The metal plates are the conductors; air is the dielectric.

You will now examine a fixed condenser to learn something about its construction. Unroll a burned-out paper *filter condenser*. You find in it several strips of tin foil or aluminum foil separated by strips of paper. You see that a condenser is made up of two or more pieces of metal separated by some kind of an insulator. Figure 134 shows a simple condenser in which air is the insulator, or dielectric.

The metal pieces are called the *conductors* because they carry, or conduct, the electricity. The insulating substance between the plates is called the *dielectric.*

Experiment. The filter condenser which you unrolled has metal foil for the conductors and several layers of specially treated paper dielectric placed between the foil conductors. You can see how such a condenser acts by stretching out the roll on a table and connecting it to a 250-volt power-supply unit. (The power-supply unit is described in Chapter 14.) The layout is shown in Fig. 135. Use it carefully, as you can receive a shock from the high-voltage connection. Before making the connections, examine the paper dielectric to see where it has burned through. Tear out this part so that the condenser will work.

Touch test points from the high-voltage tap of the power supply to the two strips of foil. If the foil strips are shorted (when the two plates touch, they are said to be *shorted*) the neon tube will glow steadily. Separate the foil at the shorted spot, and again touch the test points to the foil. If the tube no longer glows steadily, the short has been eliminated and you are ready to proceed with the experiment.

Once you have eliminated all shorts, the condenser will charge

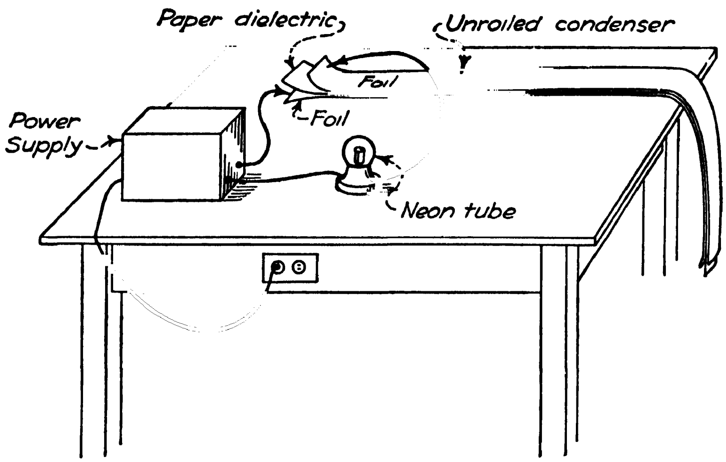


FIG. 135. This is the way to "charge" a condenser with electrons.

when you touch the test points to the foil. While the condenser is charging, the neon tube will glow. The glow dims and dies out as the condenser becomes fully charged. (A condenser of 20 microfarads will take several seconds to charge when connected to a 250-volt direct-current power supply.)

Electrons were forced into the foil conductors, as you readily saw, because you touched the blade of a screw driver with an insulated handle across the two plates *after* you had disconnected the power supply from the foil. A strong spark jumped as the connection was made.

Caution. Do this carefully, because you can get a strong shock if you touch the two pieces of metal foil or the metal blade of the screw driver when performing this test.

Why It Works. The power supply pumps free electrons *onto* the plate connected to its negative terminal and pumps free elec-

trons *off* the plate connected to its positive terminal (see arrows in Fig. 136).

As soon as the condenser plates are charged with as many free electrons as the 250 volts of the power supply can force on them, the glow in the neon tube stops, showing that the electron flow has stopped.

The neon tube showed by its bright glow, at first, that many electrons were flowing onto the negative plate and off the positive plate. As the condenser charged, or filled, its glow gradually

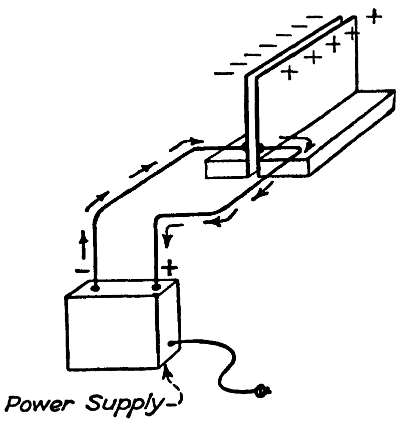


FIG. 136. As the condenser charges, electrons are forced on one condenser plate and are pulled off the other.

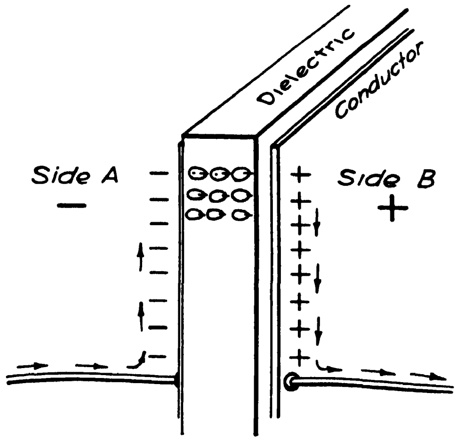


FIG. 137. An electron on side *A* repels electrons in the atoms of the dielectric which in turn repels electrons on side *B* making it positive.

dimmed and went out. What happened in the condenser as it charged?

How is the condenser charged? When electrons are forced onto one side of a condenser, as with side *A* in Fig. 137, side *A* becomes negative. The extra free electrons on side *A* affect the electrons in the atoms in the dielectric.

This effect carries through the dielectric and *repels* free electrons from side *B* of the condenser. These electrons leave side *B* and are drawn toward the power supply. Side *B* becomes positive because it has lost electrons.

This process goes on until as many electrons are forced onto side *A* and are pulled off side *B* as is possible at that voltage.*

* Charging a condenser is somewhat similar to pumping gas into a balloon. Higher pressure at the pump will force more gas into the balloon.

Each electron on the negative plate repels one on the positive plate. The dielectric is under an increasing strain as the condenser approaches full charge. If there is a flaw in the dielectric, such as a pinhole in the paper, the electrons will rush through from the negative to the positive plate and equalize the charge. The heat generated by the rush of electrons burns the paper, and we say the condenser is *burned out.*

Plate area affects the condenser capacity. Look in any radio-supply catalogue, and you will find that condensers are described as having so many *microfarads* (abbreviated μf) of capacity. You can get a rough idea of the area of a condenser plate by tearing up a 1-microfarad paper-dielectric by-pass condenser.

Since many condensers used in radio work have very small plate areas, it is convenient to give their capacity in micromicrofarads (abbreviated $\mu\mu$f), which means 1 millionth of a microfarad. You can see the effect of capacity by performing the preceding experiment, using several different sizes of paper by-pass condensers.

You find that an 8-microfarad condenser charges slowly and produces a strong spark; a 4-microfarad condenser charges more quickly and produces a weaker spark; and a 1-microfarad condenser charges even more quickly and produces a still weaker spark.

If you were to tear up these condensers- one of 8 microfarads, one of 4 microfarads, and one of 1 microfarad capacity – you would find that the 8-microfarad condenser had the largest strips of foil of the three, that is, the largest plate area.

Rule. The larger the plate area, the greater the condenser capacity.

There is more room for free electrons on a condenser plate of large area than on a plate of small area. Many electrons on side *A* can repel many on side *B*, so that a condenser with large plate area has large electron-holding capacity.

Dielectric thickness affects condenser capacity. Now try stacking several old, unrolled 8-microfarad filter condensers, one on top of another. Connect every other plate together. Put a board on top of the stack to hold them together.

If you repeat the preceding experiment, you should get a much heavier spark than before.

Rule. Increasing the number of plates in a condenser increases its capacity. This is another way of increasing the plate area of the condenser.

Now take off the board and fluff up the paper and foil, so that there is an air space between some parts of the layers. You have increased the thickness of the dielectric. Again charge the fluffed-up condenser. Note that it takes a shorter length of time to charge the condenser and that the spark is weaker when you discharge it.

Rule. The thickness of the dielectric (the space between the plates) affects the capacity of the condenser. A thin dielectric increases capacity because the plates are close together. A thick dielectric reduces the capacity because the plates are relatively far apart.

Why It Works. An electron on plate A has a certain repelling force on an electron on plate B. This force is stronger when the plates are close together but rapidly becomes weaker as the space between the plates is increased.

In a condenser with a thin dielectric, the plates are close together. This increases the repelling force that an electron on side A exerts on an electron on side B. So the closer the plates are together, the greater the capacity of the condenser.

Dielectric material affects condenser capacity. The kind of dielectric material that separates the plates also affects the capacity of a condenser.

Experiment. This can be seen if you substitute different materials of about the same thickness for the paper between the sheets of foil in your unrolled condenser.

You will need a condenser tester of the type used by radio servicemen to show the changes in capacity.

Place sheets of writing paper between the plates, and measure the resulting capacity of the condenser. Then try sheets of oiled paper, condenser paper, mica, or glass.

Write the results in the second column of a table like the one in Fig. 138. This will enable you to compare the condenser capacity that you obtained with the different dielectric materials.

Look up in a good radio handbook the dielectric constant K for the different materials you used in your test, and compare them with the ones you found in your experiment.

Why It Works. As you learned, the dielectric is the insulator that separates the condenser plates; it prevents electrons from jumping from one plate to the other but transfers energy from one

plate to another, so that an electron on one plate can drive off an electron on the other plate.

In poor dielectrics the energy is lost in heat. The dielectric must be a good insulator, because, as you will find later, the electrons must *go around* through the circuit and not go directly from plate to plate through the dielectric. High voltages are used on condensers in some radio circuits. Their dielectric must be able to stand high voltages. Too great a voltage will break a glass dielectric and allow a spark to flash through. If the dielectric is paper, the spark burns a small hole. The carbonized paper around

Dielectric	Capacity of Experimental Cond	Dielectric Constant
Air		1
Glass		7 to 8
Mica		2.5 to 8
Wood		25 to 6
Cardboard		25 to 5

FIG. 138. Write the approximate dielectric constant that you observe from your condenser test in the table shown here.

this hole will then carry the electrons through instead of keeping them separated on the plates.

The dielectric constant K is a number that tells how much more effective a given dielectric is than air. Air has a K of 1, glass from $4\frac{1}{2}$ to 7, mica about 7. This means that when glass is used as the dielectric, a given condenser will have from $4\frac{1}{2}$ to 7 times as much capacity as if the dielectric were air, and when mica is used, the capacity will be 7 times greater than if the dielectric were air. The K for paper treated with titanium oxide may run as high as 40 to 60. A condenser with a treated-paper dielectric would have from 40 to 60 times the capacity of one with an air dielectric of the same thickness.

How do you calculate condenser capacity? You can blend the several facts you have learned about condensers into a statement

that you can use to find the capacity of any two-plate condenser. You must know the area of each plate, the dielectric thickness, and the dielectric constant for the material.

The capacity of a condenser in micromicrofarads is found by multiplying the area of the plates in square inches by the dielectric constant and then by the constant 0.224. Finally, you divide this answer by the thickness of the dielectric in inches to get the capacity of the condenser.

You can write this out much more easily as a formula:

$$C = \frac{0.224KA}{T}$$

where C means total capacity in micromicrofarads
K means the dielectric constant
A means the area of one conductor in square inches
T means the thickness of the dielectric in inches

Example. What is the capacity in micromicrofarads of a filter condenser like the one you tore open, if each of the two pieces of foil is 4 inches wide by 20 feet long, if the paper dielectric is 0.005 inch thick, and if the dielectric constant, or K, is 55?

Step 1. Write down the formula

$$C = \frac{0.224KA}{T}$$

Step 2. Write down the numbers you have to work with

$$\begin{aligned} K &= 55 \\ A &= 4 \text{ in.} \times 20 \text{ ft.} \times 12 \text{ in. per foot} \\ &= 960 \text{ square inches, the area of one plate} \\ T &= 0.005, \text{ or } \tfrac{5}{1000}, \text{ inch} \end{aligned}$$

Step *3.* Substitute the numbers in the formula.

$$C = \frac{0.224 \times 55 \times 960}{\frac{5}{1000}}$$

Step 4. Do this multiplication and division *one step at a time.* First, multiply 0.224 by 55.

$$\begin{array}{r} 0.224 \\ \times\ 55 \\ \hline 1\ 120 \\ 11\ 20 \\ \hline 12.320 \end{array}$$

Next, multiply 12.32 by 960.

$$\begin{array}{r} 12.32 \\ 960 \\ \hline 73920 \\ 11088 \\ \hline 11827.20 \end{array}$$

Now that you have all of the multiplication done, the problem looks like this

$$C = \frac{11827.2}{\frac{5}{1000}}$$

Step 5. Remove the fraction $\frac{5}{1000}$ by inverting it and multiplying, as shown

$$11827.2 \times \frac{1000}{5} = \frac{11827200}{5}$$
$$= 2{,}365{,}440 \text{ micromicrofarads}$$

This is the answer.

Step 6. Divide this answer by 1,000,000 to get microfarads.

$$\frac{2365440}{1{,}000{,}000} = 2.36 \text{ microfarads}$$

Questions

1. What is the purpose of a condenser?
2. Describe the construction of a condenser.
3. What is a variable condenser?
4. What is a dielectric?
5. Describe how to test a condenser to find out if it is shorted.
6. What is meant by the term *capacity* when we speak of condensers?
7. Give several ways for changing the capacity of a condenser.
8. Explain the meaning of the dielectric constant K.
9. What would be the capacity of the condenser described above if three layers of paper were used for the dielectric?
10. What would be the effect on the capacity of the condenser if the metal foil were only half as long, that is, 10 feet instead of 20 feet?

How does a variable condenser work? Examine the variable condenser again. Note the size of its plates, their shape, and the spacing between the plates. The capacity of the condenser depends on the number of plates and on the spacing between them. Large-sized plates have more capacity than small ones if the spacing is the same. The closer the spacing, the higher the

capacity, but if the plates are too close, a spark may jump across the plates when high voltage is used.

When electrons are forced on one set of plates, they repel electrons on the other set of plates. This is shown in Fig. 137.

But when the rotor plates are swung around so that the area of the rotor plates between the stator plates is larger (see shaded areas, Fig. 139) more electrons are forced off the stator plates, and, as a consequence, the capacity of the condenser is greater.

Only the parts of the plates that are opposite each other (the shaded area) are working. Thus you can see that turning the

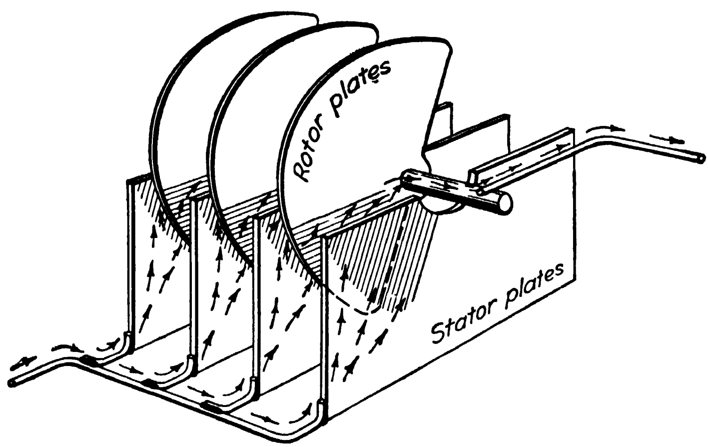


FIG. 139. Electrons on the stator plates of this condenser repel those on the rotor plates only in the shaded areas.

rotor plates merely changes the working area and, thereby, the capacity of the condenser. When the plates are completely meshed, the capacity is greatest.

What happens in the condenser in your set? First, draw a schematic diagram of the antenna and the tuning circuits like the one in Fig. 140. The arrows along the antenna circuit show that electrons surging downward in the antenna-to-ground circuit flow through the primary coil and induce a voltage in the secondary coil.

Note that this voltage in the secondary *drives electrons onto side A* of the variable condenser and *pulls them off side B*.

You can easily see that the condenser plates have to be at a certain setting so that the condenser will fully charge by the time

the downward surge in the antenna is completed and the upward surge starts.

On the upward surge, shown in Fig. 141, the electrons in the secondary are pulled off *A* and are forced onto *B*.

Now you must again study alternating current to learn about a new effect it sets up in a coil

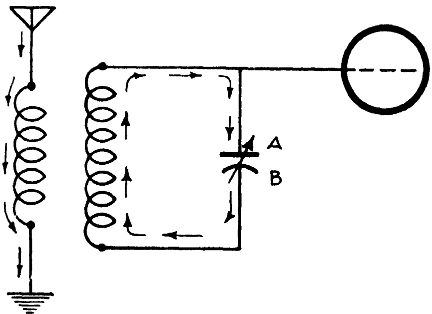


FIG. 140. The arrows on this schematic circuit diagram show the direction of current flow through the tuning circuit of a radio receiver. When the current in the antenna-to-ground circuit flows in this direction, electrons are forced on side *A* and are pulled off side *B* of the variable tuning condenser.

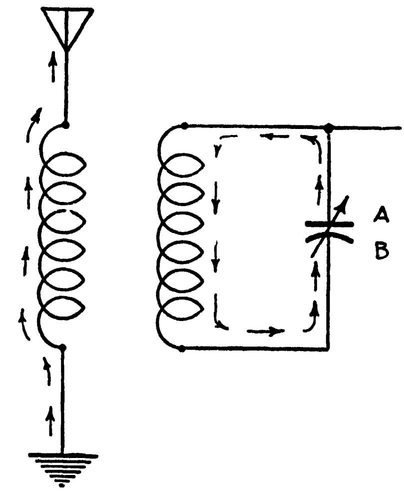


FIG. 141. This shows the action of the electrons when the current in the antenna-to-ground circuit reverses. Electrons are now pulled off side *A* of the variable condenser and are pushed on side *B*.

and a condenser, information you will need so that you can understand tuning.

PART 4: HOW CHOKE COILS WORK—INDUCTANCE

When studying direct currents in an earlier chapter, you learned that the ease with which electrons drift through a wire depends upon the resistance of the wire, which in turn depends upon the size of the wire, the material of which it is made, its length, and its temperature. Let us think of this resistance from now on as the *direct-current resistance.*

Experiment: A Choke Coil and Lamp

A completely new effect takes place when an alternating current flows through a wire.

Hookup and Operation

Lay a piece of No. 24 enameled wire, 200 or so feet long, on a bench or on the floor in a haphazard fashion. *Do not coil it.* Connect a 40-watt light in series with the wire, as shown in Fig. 142. Plug the extension cord into a wall outlet.

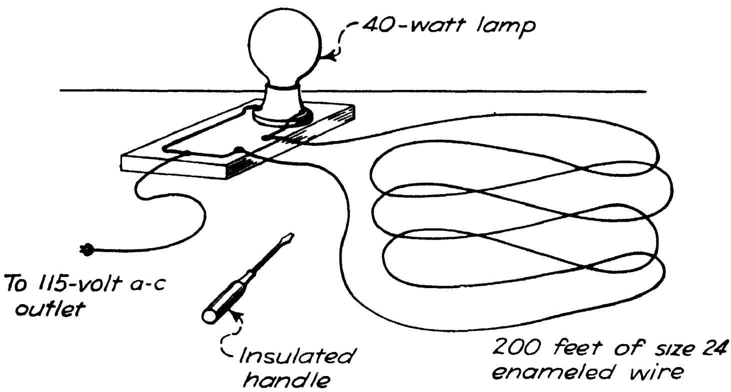


FIG. 142. The light dims slightly because the wire has resistance.

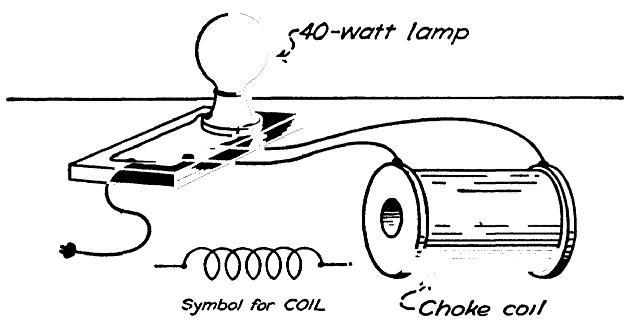


FIG. 143. When the wire is wound into a coil, the lamp is much dimmer than it was when the wire was spread out loosely.

First, touch a screw driver across the two binding posts to which the wire is connected. The lamp will burn at full brilliance.

Then remove the screw driver to see how much the resistance of the wire dims the lamp.

Now wind the wire on a cardboard tube 1 inch in diameter (see Fig. 143). This is called a *choke coil.* Wrap the ends of the wire around the two screws on the wooden endpieces. Be sure to scrape the insulation off the enameled wire, so that it will make contact with the screws. Connect the two screws to the clips on

the lamp board, and reconnect the extension cord to the wall outlet.

You find that the lamp is much dimmer than before. But why? You are now ready to learn the reason that a wire, when wound into a compact coil, reduces the current and the brilliance of the light.

Why It Works

What is back voltage in a coil? A voltage induced *inside* the winding of the coil itself dimmed the lamp. Figure 144 shows a few turns of the coil, greatly magnified.

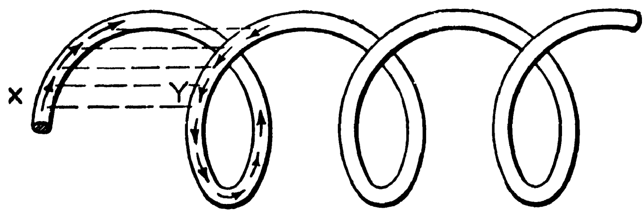


FIG. 144. The original current shown by → induces an opposing voltage, shown by ⟶, in the nearby turns of the coil.

You have learned how induction occurs between two coils. You may be surprised to know that induction can also occur *between the loops, or turns, of a single coil.* The turns of wire are placed close together on radio coils, because you want to make use of this induction between turns to help pick out, or tune in, the stations you want to hear.

If you wound a primary and a secondary coil of one turn, you still would find that a weak voltage was produced in the secondary coil whenever the strength of the current in the primary was changed. This effect is shown in Fig. 144.

When a current starts to flow in a coil, as at X, it sets up a voltage in the opposite direction, as at Y. This occurs all along the coil whenever the strength of the current changes.

During the instant that the current strength is increasing, the field around the wire is expanding outward. As the field from X passes through the wire at Y, it sets up a voltage in this part of the wire. You learned that the induced voltage flowed in the opposite direction to the primary current.

The induced voltage sets up a current at Y which *flows back* against the original current at X and meets it head on. So you can see that as the current flows through the wire it induces an opposing voltage in the nearby turns.

The induced voltage is weaker than the original voltage, because the magnetic field weakens as it passes through air between turns.

When the wires are small and close together, the field set up by the current flowing in one turn reaches several nearby turns and induces in each a voltage. This induced *back voltage* opposes the original voltage, so that less current will flow through the coil, and the lamp dims. The technical name of this back voltage is *inductive reactance.* The reactance, or back voltage, is produced by the *inductance* of the coil.

Since the back voltage reduces the original current, it is sometimes thought of as producing the same result as a resistance.

Alternating-current resistance is equal to back voltage plus direct-current resistance. You must remember that the atoms of the metal wire resist the flow of electricity. This is the *direct-current resistance* you studied earlier.

So the total opposition to the flow of alternating current is caused by two things: one, the back voltage, or reactance, and the other, the direct-current resistance. The total effect of these two combined effects that make up alternating-current resistance is called *impedance,* to keep it from being confused with simple direct-current resistance.

What are some practical applications of the choke coil? Choke coils are used in many places in radio circuits. You will soon learn how a choke coil opposes the flow of an alternating current but allows a direct current to flow freely in a receiver. When current flows through a resistor, energy is lost as heat, but when a choke coil opposes the flow of alternating current, no appreciable energy is lost.

You can use a choke coil with an adjustable plunger to control the current flow in an alternating-current circuit.

Experiment

Hookup. Connect a 40-watt lamp in series with a choke coil, as shown in Fig. 145. Use the double-pole double-throw (dpdt) switch, as shown here. Connect B batteries to one set of con-

tacts of the double-pole double-throw switch. They should furnish 115 volts of direct current.

Connect the other two points of the double-pole double-throw switch to the 115-volt alternating-current outlet.

Operation. First, throw the switch so that the batteries are connected to the lamp, and note the lamp's brilliance. Try moving the core in and out of the choke coil to see the effect it has on the brilliance of the light. Work rapidly, because the batteries run down very quickly when connected to a lamp.

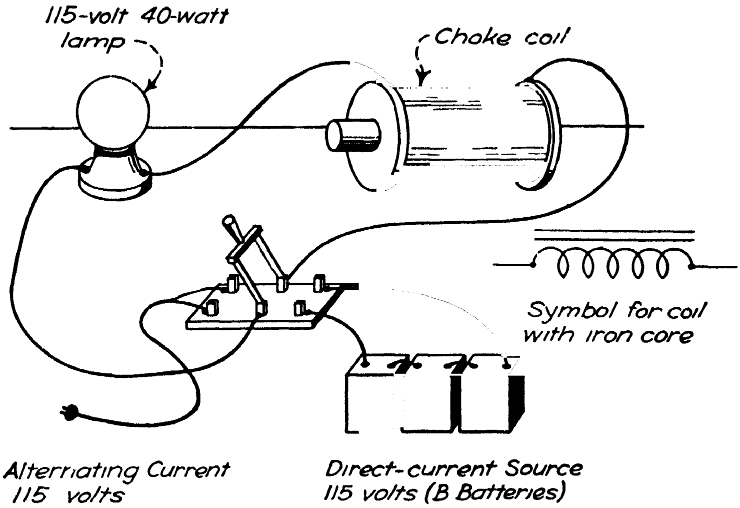


FIG. 145. Use this circuit to see the effect of the choke coil when a direct current or an alternating current flows through it. Watch for any difference in the glow of the lamp.

Now throw the switch to connect the choke coil and lamp to the alternating-current supply, and notice the effect on the brilliance of the lamp. Note the effect of moving the core in and out of the coil. The lamp is brighter when the core is all the way out of the coil than when it is all the way in.

Why It Works

You saw in this experiment that the choke coil has little or no effect on the strength of a steady direct current. Direct current flows readily through the choke coil, with only a slight loss owing to the resistance of the wire in the coil.

But when you used an alternating current, the lamp dimmed, showing that a back voltage was set up in the coil.

When you pushed the core all the way in the coil, you increased the magnetic effect of the coil and the amount of back voltage, thereby reducing the brilliance of the lamp. You will find a choke coil used in radio circuits where you wish to allow a direct current to flow and, at the same time, wish to reduce the flow of an alternating current. You will find an air-core choke coil used for this purpose in the regenerative detector circuit, as well as in transmitter circuits.

What Happens When the Current in a Choke Coil Dies Out?

You found that when a direct current begins to flow in a choke coil, it induces a voltage in the nearby turns of the coil which hinders the flow of the original current. What will happen when you shut off the current, and the field of force around the wires of the coil collapses?

Examine the diagram in Fig. 146. As the lines of force collapse back toward the primary wire, they are moving in the direction opposite to that of Fig. 132, where the primary current was growing.

As the lines of force move past the secondary wire, part of their energy is used to move electrons in that wire. The left-hand rule tells us that the collapsing lines of force induce in the secondary wire a voltage which drives the electrons in the direction opposite to that shown in Fig. 132, when the current was first turned on.

This means that when the current dies out in the choke coil, the back voltage produces a current that flows in the **same** direction as the original current. This back voltage tries to keep the original current flowing. An experiment will show you this effect.

Experiment

Find an electrodynamic (electro-dynamic) speaker with a low-resistance field winding. These speakers, common in the early days of radio, used a storage battery to supply field current. Connect wires to the dynamic-speaker field. Touch the metal clips on the ends of the wire to the terminals of a storage battery. You will see no spark and get no shock when you make the attachment, because the voltage is so low. Hold the terminals on the

battery while you count to 10 slowly. Then remove one clip with a scraping motion. You should see a spark, and you will get a light shock.

Why It Works

When you touched the clips to the battery, current immediately began to flow through the field winding. The magnetic field

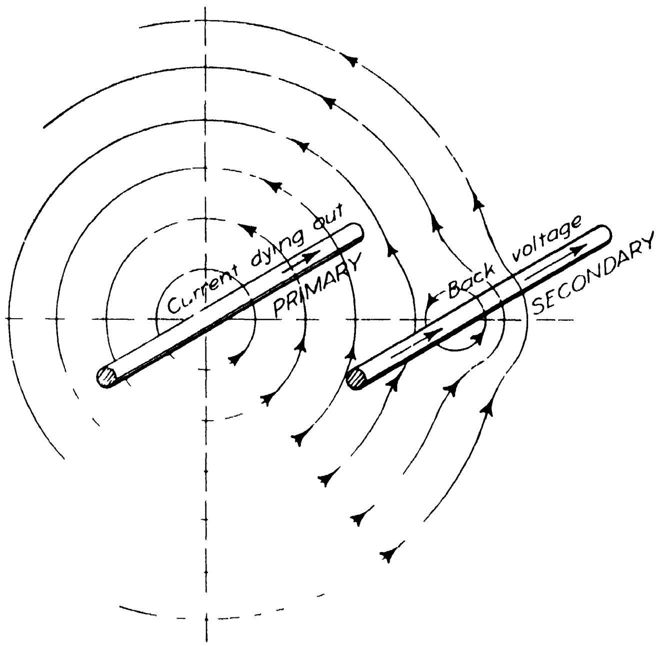


FIG. 146. The current is dying out in the primary wire. As the field around the wire collapses, there is set up in the wires a back voltage which tries to keep the original current flowing. Note that this back voltage is in the *opposite* direction to the back voltage that occurs when the current *starts* to flow through the wire.

around the winding required a fraction of a second to build up, because the back voltage opposed the growing current. Since there are many hundreds of turns of wire and a large iron core in the field coil, a strong field is built up.

But when you scraped the clip away from the battery terminal, you noticed a spark and you felt a shock. Why did you get both a spark and a shock from a 6-volt battery? Back voltage at the time the circuit was broken caused this shock and the spark. When the current was turned off, the intensely strong magnetic

field suddenly collapsed. As the lines of force whipped swiftly past the hundreds of turns of wire in the field winding, they induced a small voltage in each wire. Since the wire of the coil is continuous, the hundreds of weak voltages added and produced a stronger back voltage than the original 6 volts of the storage battery.

Summary of the Principle of Self-induction

Let us bring together the facts that you have learned about back voltage.

1. You know that when a current starts to flow, it will generate *in the coil* a back voltage that opposes the original current.

2. You know that less alternating current will flow through a coil of wire than through the same wire laid out straight.

3. You know that when a core is put into the coil, the back voltage is much stronger and still less current flows.

4. You know that when the current in the coil is shut off, a back voltage again is set up, now in the direction of the original current.

Rule. The choke coil opposes any current change. It tries to stop, or hinder, a current that is starting and it "pulls," or tries to keep flowing, a current that wants to stop.

PART 5: WHAT REACTANCE IS AND HOW IT IS FOUND

What effect has a choke coil on current and voltage? Both the electrical engineer and the radio engineer are concerned with the effect of a choke coil on both current and voltage when they design circuits. You can connect a lamp to the oscilloscope and show on the screen that the current and voltage work together when they flow through the filament.

The oscillograph would show that the instant the electricity is turned on in a lamp, both voltage and current curves rise and fall together. The sine curve in Fig. 147 shows this happening.

This sine wave shows both the alternating current and the alternating voltage. You get overlapping sine waves because both current and voltage become strong and weak at the same time. They are in step, or in phase. You can use the electrical term *in phase* to describe two conditions occurring together in step, or at the same time.

However, when you try to show the sine waves of the current and voltage that flow through a choke coil and lamp circuit, you then see two curves, one ahead of the other (see Fig. 148). A special switching circuit must be used.

When a current of electrons starts through a coil, it at once is opposed by the current set up by the induced back voltage. Just what happens can be seen on an oscilloscope. The current and the voltage sine waves trace patterns, as shown in Fig. 148.

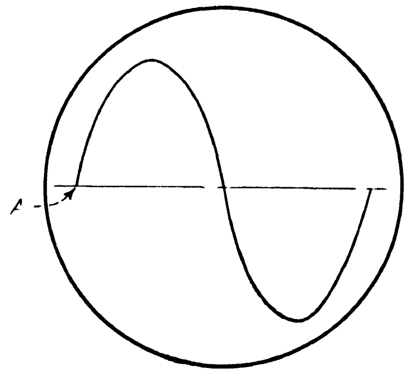


FIG. 147. This is the combined sine wave of the alternating current and voltage applied to the lamp shown in the circuit of Fig. 142. Note where the curve starts at *A*.

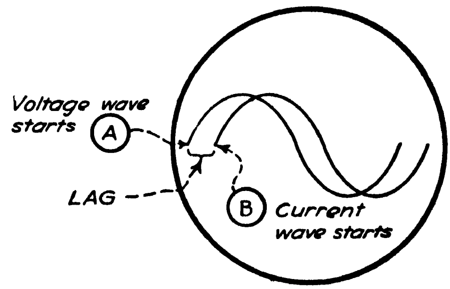


FIG. 148. This is the kind of wave picture you should see on the oscilloscope for the choke coil and lamp shown in Fig. 143. It shows both the sine curve for current and the curve for voltage as they are forced out of phase by the action of the choke coil.

Note that the voltage sine wave starts at the left of the screen. Also note that the sine wave for current starts almost one-quarter of the way across the screen.

The distance to the right that the current wave starts behind the voltage wave is called *lag* of the current behind the voltage. This is the time it takes for the current to grow to full strength after the voltage reaches full strength. The lag is the result of the back voltage of the coil. We now say that the current and voltage are *out of phase*.

Why it works. When the lamp, which has resistance only, was in the circuit alone, both current and voltage went together from full strength to zero and on to full strength in the opposite direction. There was no back voltage in the circuit. But when you

connected the choke coil in the circuit, its back voltage made the current grow to full strength later than the voltage did. The voltage rose to full strength almost instantly. But the electrons meeting other electrons pushed back through the wire by the back voltage reached full strength after the voltage had gone on almost another quarter cycle. So we say that when a choke coil is in the circuit, the voltage leads the current by 90 degrees. The voltage and current are now almost 90 degrees *out of phase.*

Why is the back-voltage effect important? Why does one coil produce little back voltage, while another produces a great deal? It is important for the radio designer to know accurately the amount of back voltage produced by a coil in a radio circuit, because he uses reactance, or the back-voltage effect, for tuning.

What things affect the back voltage of a coil? In the choke-coil experiments, you found that a coil with many turns produced more back voltage than one with few turns. You also found that putting an iron core in a coil increases the back voltage. These different things that affect voltage can be gathered into a formula, which you can use to find the back-voltage effect for coils of many different sizes. The answer found by working out this formula is the *inductance* of the coil.

Inductance is the measure of a coil's ability to set up a back voltage. Here is the formula for inductance and the meaning of the letters in it.

$$L = \frac{(r^2n^2)}{9r + 10l}$$

where L = the total inductance of the coil in microhenrys. (A microhenry is $\frac{1}{1,000,000}$ of a henry.)

l = the length of the coil in inches.

r = the radius of the coil in inches. (The radius is half the diameter.)

n = the number of turns of wire in the coil.

This formula may look mysterious, but when it is applied to an actual coil, it will become a sensible and useful radio tool. Why were the different letters put into the formula?

Why are r^2 and n^2 used? A long coil has more inductance than a short coil because there are more turns of wire in it. You must

multiply the number of turns of wire, n by itself n^2 (read n square), because the magnetic field around a single wire reaches out and sets up a back voltage in the nearby wires. If the magnetism affected only the nearest wire, the n would not be squared. This effect is great enough so that we not only square the number of turns n^2, but we also square the radius of the coil r^2.

How do you work out the formula? The secondary of the tuning coil in Fig. 127 was wound with 60 turns of No. 24 enameled wire on $1\frac{1}{2}$-inch diameter coil form. It was wound in one layer and was $1\frac{1}{4}$ inches long. First, make a list of the facts you will need for your formula.

L = the inductance in microhenrys to be found by working out the formula
l = $1\frac{1}{2}$ inches (length of the coil)
r = $\frac{3}{4}$-inch radius (half of the $1\frac{1}{2}$-inch diameter)
n = 60 turns
$n^2 = 60 \times 60 = 3600$

How to Read the Formula

$$L = \frac{(r^2n^2)}{9r + 10l}$$

Read the formula in this way: The top line is read as r squared n squared. As written, it means to multiply r times r times n times n. The bottom line, $9r + 10l$, means to multiply 9 times r and then add this answer to 10 times l.

The line between the two sets of numbers means that the answer above is to be divided by the answer below. This gives the answer to the problem in microhenrys of inductance.

Now substitute your facts in this formula

$$\begin{aligned} L &= \frac{(r^2n^2)}{9r + 10l} \\ &= \frac{(\frac{3}{4} \times \frac{3}{4}) \times (60 \times 60)}{(9 \times \frac{3}{4}) + (10 \times 1\frac{1}{2})} = \frac{\frac{9}{16} \times 3600}{6.75 + 15} \quad \text{Multiply before you add.} \\ &= \frac{2025}{21.75} \\ &= 93.1 \text{ microhenrys} \end{aligned}$$

The total inductance of the coil is 93.1 microhenrys.

Uses of reactance, or back voltage. Reactance, or back voltage, the effect produced when a current flows in a coil, is used in many ways in radio circuits. The back voltage produced in a given coil depends on the inductance of the coil. Later on you can use the inductance in a simple formula that will help you in planning the tuning circuit.

In the next chapter you will find how the back voltage of the coil and of the condenser can be used to tune your receiver to stations you want to hear.

How is reactance found? Reactance is found by using a simple formula. It was discovered by experiment that a coil with a certain inductance would set up a definite back voltage. The hindering effect in the circuit caused by back voltage is measured in ohms, even though it is produced in a manner different from resistance. It was also found that the *rate* (the number of times per second) at which the alternating current changed direction also affected the back voltage. This is the formula that was worked out from many experiments.

$$X_L = 2\pi f L$$

How is this formula read? Read this formula as follows: Reactance of a coil, *in ohms*, equals two times pi times frequency in cycles per second times inductance in henrys.

Where X_L, read as X sub L, represents the reactance of a coil at a given frequency owing to its inductance. The answer will be in ohms.

π, the Greek letter pi, equals 3.14. $2\pi = 6.28$.

f represents the frequency of the alternating current (the number of electron round trips per second).

L represents the inductance in henrys that you have just learned how to work out.

Now apply this reactance formula to find how much reactance is possessed by the secondary coil whose inductance you just calculated. This coil has 60 turns of No. 24 enameled wire wound on a form 1½ inches in diameter. Assume that you are interested in the reactance of the coil at 1,000,000 cycles per second, which is near the middle of the broadcast band.

Write out the values you know

X_L = value to be found
$2\pi = 2 \times 3.14 = 6.28$
f = 1,000,000 cycles
L = 93.1 microhenrys, the value you found for the secondary coil (0.0000931 henry)
$X_L = 6.28 \times 1{,}000{,}000 \times 0.0000931$
$= 584.6$ ohms

PART 6: HOW BACK VOLTAGE OCCURS IN A CONDENSER

What is the reactance of a condenser? The back voltage effect, or reactance, also occurs in a condenser. When free electrons are

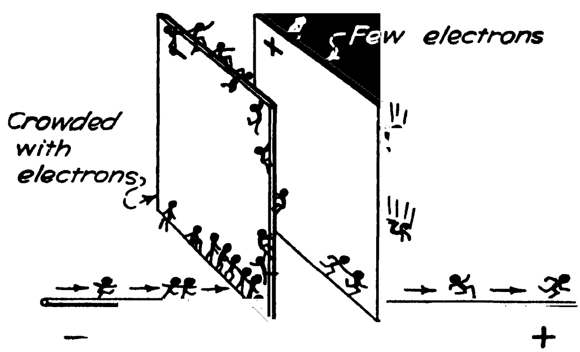


FIG. 149. Electrons already on the negative plate of the condenser repel others trying to get on the plate. Because the positive plate is short of electrons, it "pulls" back on those trying to leave.

forced on the plates of a condenser, a back voltage is set up, but it occurs for a different reason than back voltage in a coil.

As electrons first rush into a condenser, there are few extra free electrons on the plates. Back voltage builds up, however, as the number of free electrons on the negative plate increases and as the free electrons are pulled off the positive plate. All the free electrons on the negative plate repel the others trying to get on the plate (see Fig. 149). The positive plate, which needs electrons, tries to hold onto those that are being pulled off.

As the number of free electrons on the negative plate nears the total that the plate is able to hold, the back voltage increases until it finally stops oncoming electrons altogether, when the con-

denser is fully charged. The back voltage then equals the voltage forcing electrons into the condenser. A similar, but opposite, action takes place on the positive plate. Here the pull of the plate, which needs free electrons, becomes enough to equal the pull of the external voltage, and no more electrons flow.

How does current lead voltage in a condenser? Because the free electrons can rush into the condenser easily when it begins to charge, no back voltage occurs. But as the condenser nears full charge, the back voltage builds up rapidly, as you learned above. So you say that the current leads the back voltage in a condenser, because there is little back voltage when the condenser is empty (uncharged) and the charging current is just started, and the back voltage is greatest when the condenser has become charged and the charging is almost stopped. The formula for capacitive reactance is $X_c = 1/2\pi fc$.

PART 7: HOW IMPEDANCE—ALTERNATING-CURRENT RESISTANCE—IS WORKED OUT

There still is another effect, that of the direct-current resistance of the circuit, which you must take account of when studying alternating-current resistance. How is it handled in any problem?

The reactance (back-voltage effect) that you worked out showed only part of the hindering effect set up by the coil when it was put in the circuit with a lamp. The alternating current flows through a coil against the resistance of the metal wire. The resistance cuts down the flow of alternating current. Thus both reactance and resistance add together in some way to form the total hindering effect that is known as *alternating-current resistance*, or *impedance.*

However, you cannot add 30 ohms caused by wire resistance in the coil to 40 ohms of reactance and get 70 ohms of impedance. You will find that this answer is incorrect. There would be only 50 ohms of impedance.

There is an easy way to show how to combine resistance and reactance. You know that the current lags behind the voltage in a coil. You also know that the voltage and current in a resistor are in phase. You can use a diagram to find the impedance. This diagram is called a *vector diagram.* You use geometry instead of arithmetic to work out the answer. You first draw an arrow

that is as many units long as the number of ohms in the resistance. If the resistance is 30 ohms, the R arrow will be 30 units long. (You could use $\frac{1}{4}$-inch units; the R arrow then would be $7\frac{1}{2}$ inches long.)

Now draw another arrow, the X_L (inductive reactance) arrow, up from and at *right angles* to the R arrow; make it 40 units long. Then connect the ends of the R and X arrows with a third line Z to form a right triangle. Measure the length of the Z arrow. You will find that it is 50 units ($12\frac{1}{2}$ inches) long. You read it as 50 ohms impedance. This is the value of Z, the impedance of the coil.

You also can work out these values by what is known as a *square law*, which is written

$$Z^2 = X^2 + R^2$$

You can also write this law as

$$Z = \sqrt{X^2 + R^2} \text{ (} Z \text{ equals the square root of } X^2 + R^2\text{)}$$

Now find the value of Z, using this formula

$$Z^2 = X^2 + R^2$$

where Z = What you want to find.

$X = 30$

$R = 40$

$Z^2 = 30^2 + 40^2$

$Z^2 = (30 \times 30) + (40 \times 40)$ Do all multiplication before you add.

$Z^2 = 900 + 1600 = 2500$

$Z = \sqrt{2500} = 50$ ohms (50 equals the square root of 2500)

This value of 50 ohms is the impedance.

What is the explanation of this formula? When the current tries to flow in a coil, it is hindered by the resistance of the wire itself. It is also hindered by the back voltage set up in the coil by the changing current strength. But since the current lags behind the back voltage, you must use this geometrical method to "add" direct-current resistance and reactance in an alternating-current circuit. When the current tries to flow into a condenser, it meets not only the resistance of the metal of which the plates are made but also the back voltage set up by electrons on the

plates. Current now leads the voltage. The formula for the reactance of a condenser now is

$$X_c = \frac{1}{2\pi fc}$$

Where are reactance and impedance used in radio? In this chapter you have spent much time studying the theory that explains how free electrons act as they surge in and out of coils and condensers. This information is needed so that you can understand how electron surges act when induced in the secondary of the coil and the set can be tuned by the variable condenser so that you can hear any broadcasting station that you wish. This is the basis for the selector, or tuning, circuit that you will study in the next chapter.

Questions

1. What is reactance? Try to explain it with as simple words as possible.
2. What is a choke coil?
3. Distinguish between inductance, reactance, and impedance. Give an illustration of each.
4. What is the difference between induction and self-induction?
5. What is meant by current lag?
6. What do we mean by saying that the current and voltage are 90 degrees out of phase?
7. What would be the inductance of a coil made of 35 turns of No. 18 enameled wire if the coil were 3 inches long and 3 inches in diameter?
8. What would be the reactance of the coil described on page 200 if 1,500,000 cycles were used instead of 1,000,000?
9. What would be the impedance of the circuit mentioned on page 202 if the reactance R equaled 40 ohms and the resistance X_L of the wire equaled 30 ohms?

Technical Terms

back voltage—The opposing voltage which a current induces in a coil.
capacitive reactance—Back voltage which is set up in a condenser.
capacity—The quantity of electrons that a given voltage can force into a condenser. Capacity is measured in microfarads or in micromicrofarads.
choke coil—A coil used to limit the flow of alternating current in a circuit.
condenser—Two metal plates separated by an insulator.
conductor—A wire, or other material, which carries a current.
core—The iron center around which the primary and secondary are wound.
current lag—When current flows into a coil, the back voltage occurs early and causes the current to lag behind the voltage.
current lead—In a condenser the back voltage occurs late, allowing the current to lead the voltage.

dielectric—The insulator between the conductors, or plates, of a condenser.

dielectric constant K—A number which compares the dielectric qualities of a given material with those of air.

electromagnet—When a current flows through a coil of wire the coil acts like a magnet. It is called an electromagnet.

impedance—The combination of reactance (back voltage) and resistance.

inductance—The property of a coil which makes possible back voltage. Inductance depends on the number of turns, the wire size, the presence of a core, and the length of the winding.

induction—Process by which an alternating current is induced in the secondary of a transformer when an alternating current or a pulsating direct current flows in the primary. The two coils are linked only by magnetism; there is no other electrical connection.

inductive reactance—Back voltage which is generated in a coil.

lag, or lead—When either current or voltage gets out of step in a circuit it is said to lag or lead, depending on the conditions in the circuit.

μf—The abbreviation for microfarad.

μμf—The abbreviation for micromicrofarad.

mutual induction—Mutual induction occurs when a varying current in one coil induces a voltage in a nearby coil.

phase—Phase refers to time. When current and voltage are *in phase*, they rise and fall together. When *out of phase*, current may lead voltage. Current then rises and falls before voltage. Current may also lag voltage.

primary—The coil of a transformer in which the original, or driving, current flows.

reactance—The opposition that the inductance of a coil or the capacitance of a condenser offers to a flow of current.

secondary—The coil of a transformer in which a voltage is induced by a changing current in the primary.

short—When wires that run from a power source to a load, such as a lamp or a transformer, touch together, they are said to be "shorted," and a heavy current flows.

transformer—Two coils, one called the primary, the other the secondary, used to raise or lower the voltage, or current. An alternating current or a pulsating direct current in the primary will induce a voltage in the secondary. No voltage is induced when a steady direct current flows in the primary; no electrical connection is made between the coils.

transformer core—A laminated, soft-iron form on which the primary and secondary coils are mounted.

tuning—The process of selecting stations. Tuning is generally done by adjusting the capacity of a variable condenser.

vector diagram—A method of working out electrical and radio problems by using lines.

CHAPTER 11

RESONANCE AND TUNING

When you connect the antenna and ground wires to your receiver, weak alternating currents flow in its antenna-ground circuit if radio waves are passing your antenna. You would like to have this alternating current cause your set to play the program that you wish to hear.

But the trouble is that your antenna may pick up radio waves from many stations at the same time. Each station that is broadcasting sends out radio waves, which, when they reach your antenna, set up a weak alternating current at the special frequency assigned to that station by the Federal Communications Commission.

You will need in your receiving set a special circuit to separate the currents set up by the radio waves from these stations, so that you can select any one station that you may want to hear. The circuit that does this is called the *tuning circuit.* In this chapter you will study two important radio fundamentals: the tuning circuit and how it operates; and resonance, or electrical cooperation, in a radio circuit.

The things you will learn in this chapter are under the following headings:

Part 1: How to Tune by Changing the Length of the Antenna
Part 2: How to Tune by a Loading Coil in the Antenna Circuit
Part 3: How to Tune by Means of a Variable Condenser
Part 4: How We Summarize the Tuning Process
Part 5: How Coupling Affects Tuning

PART 1: HOW TO TUNE BY CHANGING THE LENGTH OF THE ANTENNA

Build a set and attach an adjustable-length antenna. In this section you will build a receiving set and attach an antenna that you can change in length at will. Then you will operate the set and learn why it works.

How to Build the Set

Make the baseboard. The layout of the set board is shown in Fig. 150.

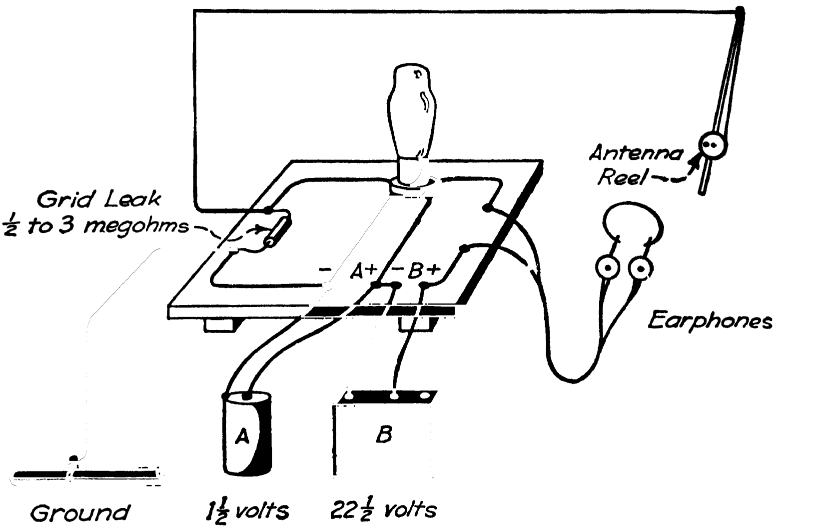


FIG. 150. The board layout for a simple receiver to use with the antenna reel.

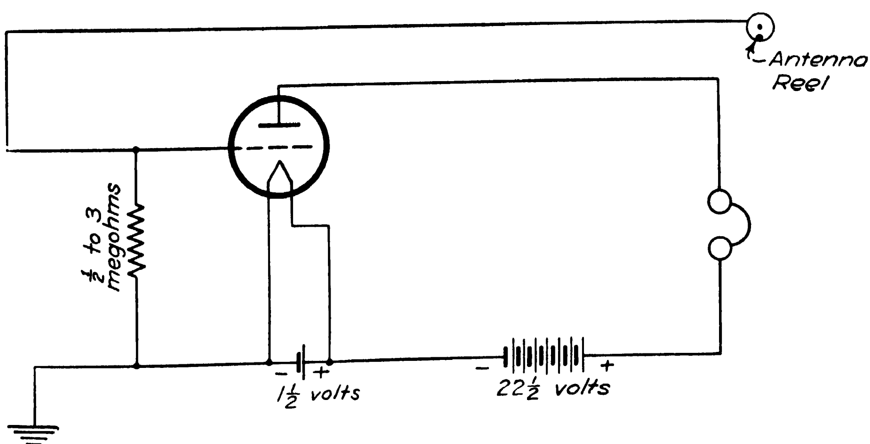


FIG. 151. The schematic circuit for the set board wired to use with the antenna reel.

Wire the set as shown in Figs. 150 and 151.

This is the same set board and circuit that you used in Chapters 6 and 7. It will be used in many experiments with both receiving circuits and power supply units.

Make the antenna reel. Make the mast of a piece of wood about 6 ft. × 1 in. × 2 in. Make a reel of three pieces of wood nailed or screwed together. The reel needs a deep groove (see Fig. 152). Attach a handle to the reel so that you can turn it as you reel the wire in or out.

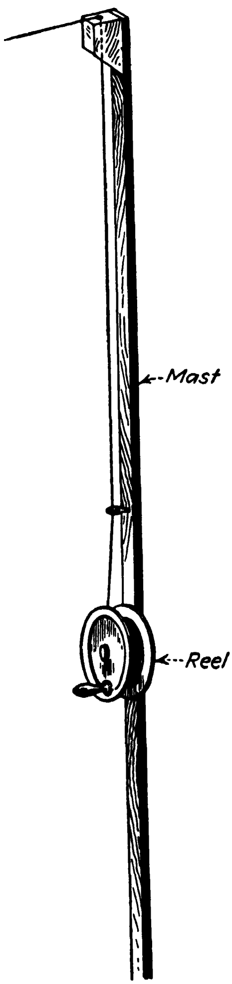


FIG. 152. How the antenna reel is constructed.

At the top of the mast, attach a wooden block through which a hole has been drilled. Round the upper end of the hole so the wire will run smoothly. Attach the reel to the mast with a stove bolt, about 18 inches from the lower end.

Wind 200 feet of No. 16 bare copper wire on the reel. Run the free end of the wire through the hole in the wooden block which is attached to the free end of the mast.

Make the antenna and ground connections. Attach the free end of the antenna wire to the grid binding post on the set. Loop the wire over a support, so that the strain on the antenna will not pull the set out of the window. Connect the ground wire to the A-negative post (see Figs. 150 and 151).

How to Operate the Set

Step 1. Connect a grid-leak resistor of ½ to 3 megohms between the filament and grid, as shown in Fig. 150.

You must find by test the size of grid leak that gives you the best results. The grid leak must be used because the grid will collect electrons on each positive surge until it becomes so negative that the tube will no longer operate.

Step 2. Connect a pair of 2000-ohm earphones to the set board, as in Fig. 150.

Step 3. Insert the 1LE3 tube in its socket, connect the A and B batteries, and the set is in operation.

Step 4. Two persons should work together on this experiment. One unreels the antenna, and the other operates the set. The one operating the set should put on the earphones and listen for stations. The reel carrier should slowly unwind the antenna as he

Bell Laboratories Record

TUNING IS SOMETIMES A VERY PRECISE PROCESS

Tuning this resonant cavity of a 60,000-megacycle klystron tube requires great precision. Tuning is assisted by use of a magnifying glass.

walks away from the building, holding the wire so that it will not touch the ground. When a station is heard, the listener should write down the number of steps the reel carrier has taken from the set.

This set tunes very broadly, which means that it will not be particularly effective in separating stations.

The reel carrier now goes farther away. When the first station fades, the set operator should again call out to find the number of steps. Keep a record of the lengths of antenna needed to tune in several nearby stations.

Check the carrier's steps as the antenna is wound in to see if the various stations reappear at about the same lengths of wire as when they were first heard. As we have said, this set is too inefficient to separate different stations completely, but it shows nicely a very simple method of tuning. It will pick up considerable hum if it is near power wires or lighting circuits, but the signals should be heard through the hum.

Questions

1. Why must the antenna be prevented from touching the ground?
2. How far from the set was the person unwinding the antenna when the first station was heard?
3. Did the station increase in volume for a while as the antenna was unwound?
4. How many steps long was the antenna when this station faded out?
5. Could any other stations be heard at the same time as the first one?
6. Record the lengths of antenna for each station when it comes in and when it fades out. Graph these figures on a straight line on a piece of paper in order that you may see just how much the stations overlap.

Why It Works—The Theory of Tuning Explained

The length of the antenna affects tuning. When one part of a radio wave strikes the antenna, it causes a current to surge through the antenna-ground circuit (see Fig. 153*A*). There is enough capacity between the tube elements to allow the passage of these surges. The antenna and ground wire must be of approximately the right length for the electron surge to return to the end of the antenna before the next wave arrives. When the next wave arrives, it gives the electrons a push and starts another surge down the antenna. This antenna-ground wire will have the strongest current possible started by each passing wave.

What is the effect of too long or too short an antenna? When the antenna is too long, as in Fig. 153*B*, the electrons do not have time to surge to the ground and return to the end of the antenna before the next radio wave arrives. This wave also starts elec-

trons down the antenna. The two surges meet and their effect is almost, or entirely, killed. The result is that weak signals or no signals are heard. On the other hand, if the antenna is too short, the incoming wave and the antenna current will be out of step and the current will be reduced.

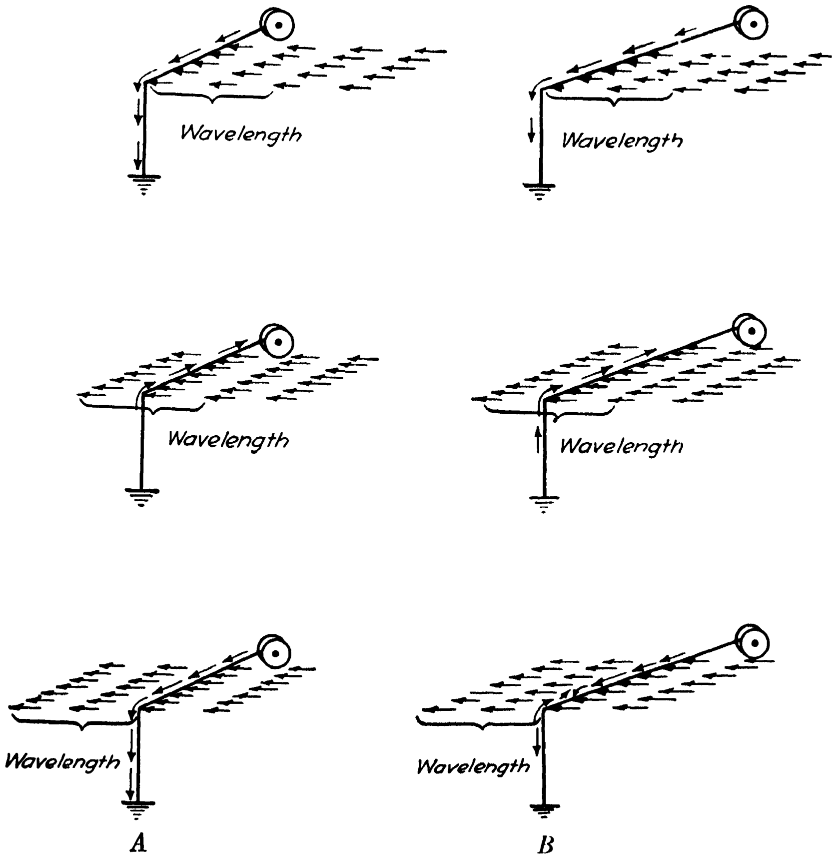


FIG. 153. How the length of the antenna affects tuning. The three diagrams at *A* show the antenna adjusted to the correct length for the desired wavelength. The antenna at *B* is too long.

There is an antenna length for each frequency. Each broadcasting station transmits on a definite wavelength, or frequency; that is, it sends out a definite number of pulsations, or radio waves, per second. This number of waves per second is different for each station. So it is possible to tune roughly to a par-

ticular broadcasting station by changing the length of the antenna to fit the timing, or frequency, of the waves it sends out.

When you do this, you are adjusting your antenna to the same electrical length as the length of the broadcasting station's antenna.

Questions

1. If the first radio wave, or impulse, that strikes the antenna happens to cause the current to flow from the ground to the antenna, in what direction will the next impulse cause the current to flow?

2. Suppose the antenna is too long. If the current flows from the antenna to the ground and has time to get just halfway back when the next corresponding radio wave arrives and sends another current down the antenna, will the currents oppose each other, or will they add and produce a greater volume of signals?

3. Suppose the antenna is too short. If the current flows from the antenna to the ground and has time to get back to the end of the antenna long before the next corresponding radio wave strikes, will you get maximum efficiency and loud signals?

4. Suppose the antenna is of such a length that the current which flows from the antenna to the ground just has time to get back to the end of the antenna when the next wave strikes. Will there be any interference among the radio-frequency surges? How will the volume of the signals compare with those in Questions 2 and 3?

5. A certain transmitting station is heard loudest when the receiving antenna is 200 feet long. Draw a diagram to show the positions of the radio waves and the radio-frequency currents for this station when you are using a receiving antenna 50 feet in length.

PART 2: HOW TO TUNE BY A LOADING COIL IN THE ANTENNA CIRCUIT

In this hookup you use the same tuning principle, but you make the mechanical tuning operation much simpler. Here you wind part of the long antenna on a tube along which runs a contact. You can change the length of antenna wire in the circuit by moving the contact instead of by reeling and unreeling the antenna.

The circuit is further simplified by the use of an antenna of fixed length built permanently in place.

How is the loading coil built? Make the coil form of a cardboard or Bakelite tube about 3 inches in diameter and about 8 inches long. Use square wooden ends to support the tube and to carry the slider rod. Have the slider run on a $\frac{1}{4}$-inch square brass rod and make contact with the bared wire by means of a spring (see Fig. 154).

How is the coil wound? Use 265 turns of enameled wire, about No. 22, for winding the coil. If you use cardboard, boil it in

paraffin for 20 minutes. This fills the pores with paraffin and keeps the form from swelling and shrinking with weather changes. If the tube shrinks, the wire will loosen. Shellac or lacquer painted on the form can also be applied instead of paraffin to prevent moisture from affecting the cardboard. Cover the inside, outside, and the ends thoroughly. If you use a Bakelite tube, no shrinkage will occur. Scrape off the insulation under the sliding contact.

What happens if other wire and tube sizes are used? If a smaller tube is used, wind on more turns. If a larger tube is

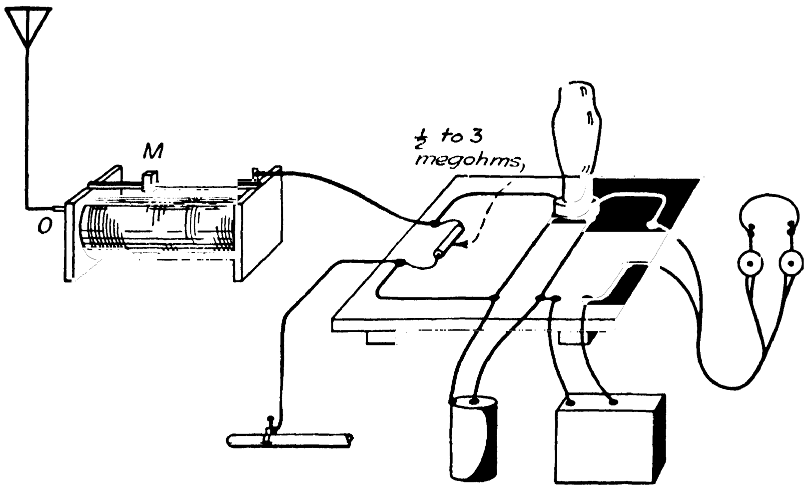


Fig. 154. How to hook up the set board to use the loading-coil tuner.

used, wind on fewer turns. The size of wire does not affect the number of turns required, but it does affect the amount of space required for the winding. If no slider can be had easily, a bare wire held in the hand and moved over the coil will act as a slider.

Questions

1. Describe a handy means of turning the coil while you are winding on the wire.
2. Would this be a satisfactory method of winding the coil?
3. What are the advantages of tight winding?
4. What are the advantages of using an insulated wire for the coil?
5. If insulated wire is used, what is a handy method for making contact with the slider?

How to Hook Up the Set

Attach the loading coil in series with the antenna as follows: Connect the antenna to the slider and connect one end of the coil to the antenna post on the tube board (see Fig. 154).

Attach the A and B batteries, the earphones, the grid leak, and the ground connection as shown in Figs. 154 and 155. The set is now ready to operate.

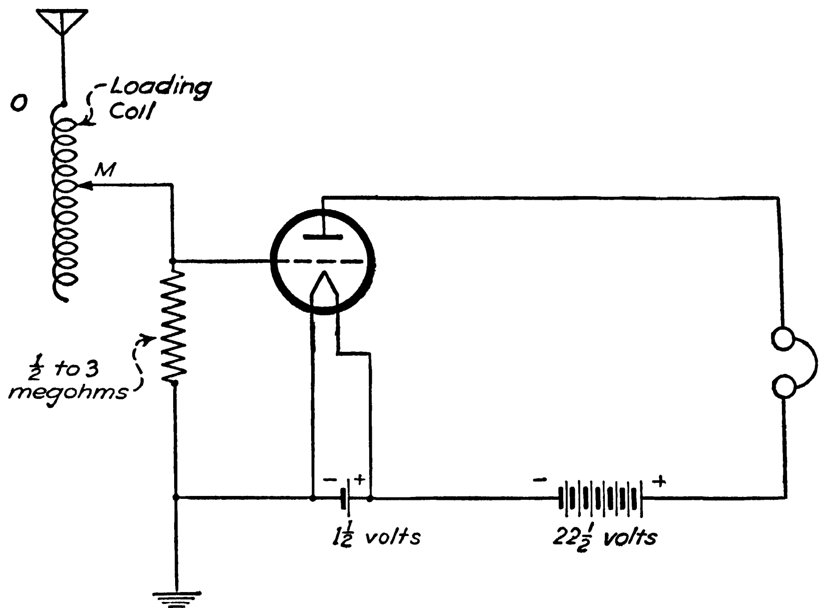


FIG. 155. Circuit diagram for the loading-coil tuning experiment.

How to Operate the Set

Start with a slider near point *O*, Figs. 154 and 155, moving the slider until you hear a station. At this point a little wire in the coil is in the circuit, and the effect is similar to using a short antenna.

Now, set the slider near point *M*, Fig. 155, and adjust it as before until a station is heard. Here the effect is the same as when you use a longer antenna.

How is the frequency of a station found? The frequencies of the different stations in your locality can be determined from the radio programs published in your local newspaper or from lists of

stations that can be obtained from your radio dealer. When wavelengths are given, the higher frequencies correspond to the shorter wavelengths and the lower frequencies are for the longer wavelengths. That is, a short antenna tunes to a high frequency and a long antenna to a low frequency.

What conclusion can you draw? It can be seen from this experiment that the coil may be used as a simple way to change the effective length of the antenna and so simplify tuning. It has not been necessary to go outside and work with the antenna at all but it has been possible to make any adjustment for tuning right on the set itself.

You may have noted that tuning was somewhat sharper with the loading coil. You should find it easier to separate stations when using it than when you used the antenna reel.

PART 3: HOW TO TUNE BY MEANS OF A VARIABLE CONDENSER

Use a transformer. In this experiment, you will use a transformer, which, as you know, has two separate windings. You will connect one of the windings to the antenna circuit and the other to the grid circuit of the tube.

Tuning the secondary of the transformer by means of a slider, as in Part 2, would be inconvenient and would be a source of noise in the operation of the set. This method also would be inefficient electrically, since the turns short easily and do not permit close tuning. A more efficient and simpler scheme for tuning the one-tube set is by means of a variable condenser shunted across the secondary coil. Much sharper and more convenient tuning is possible by means of condensers.

How to Build and Wire the Set

Make a baseboard of ½-inch pine, 9½ inches wide and 20 inches long. Screw ¾-inch by 9-inch cleats 1 inch from each end of the board on the under side. Paint or lacquer the board. This will prevent the board from soiling and will show up the wiring better.

Wind the transformer. Wind a 20-turn primary and a 60-turn secondary on a 2-inch-diameter Bakelite tube, for the receiving transformer. Use enameled wire, No. 24. Space the two coils ¼ inch apart, as shown in Fig. 156.

Use some definite system when wiring. Some system must be used when wiring a set, or wires will be left out of the circuit, and the set will not work. It is easy to burn out tubes and to ruin parts by incorrect connections. Here is a simple system of wiring that you can follow on all your sets. Wire each part of

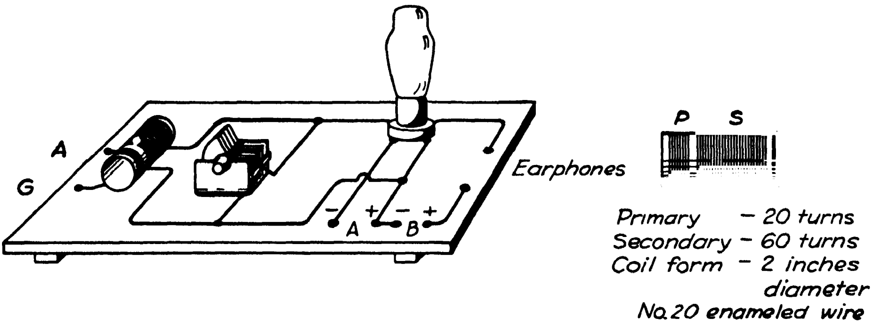


FIG. 156. Board layout for the coil-condenser tuned receiving circuit.

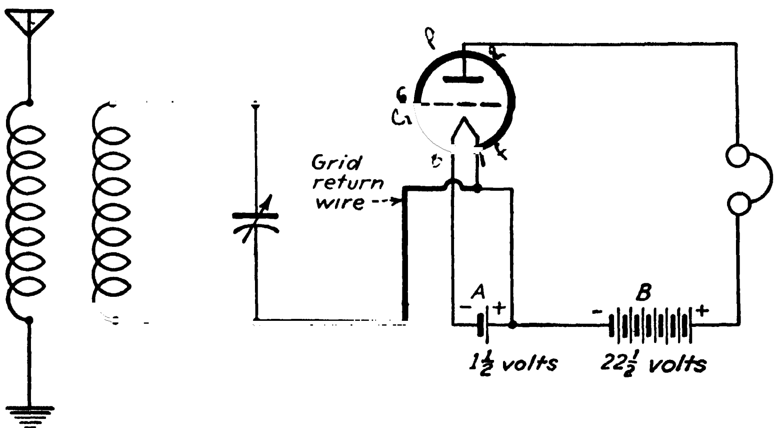


FIG. 157. This is the circuit diagram for the condenser-coil tuned circuit. Note where the wire from the condenser jumps the wire to the A-plus binding post. The dot shows where wires are joined.

the circuit separately, completing it before you start another part. This will be easy to do, if you place each part on the set board in the position it will have when connected. Refer to Figs. 156 and 157. Note that the parts are placed on the set board so that the finished board will look just like the wiring diagram shown on the schematic circuit. Use either bare tinned or enameled copper wire, No. 16, to hook up your set. If you use enameled wire,

you will have to scrape off the enamel with a knife for all joints and where you attach the wire under a binding post.

Wire the antenna-ground circuit. Connect a wire from the antenna binding post to one end of the primary coil (see Fig. 156). Connect a wire from the other end of the primary to the ground post.

Solder all connections. Bend the wires to form corners, as shown on the board layout in Fig. 156.

Wire the secondary-grid circuit. Run a wire from one end of the secondary to the grid (No. 6) on the tube socket.

Connect a wire from the other end of the secondary to the A-positive terminal (No. 1) on the tube socket. This wire is called the *grid return* and is connected to the positive side of the filament.

Now connect a wire from the stator, or fixed plate, of the condenser to the grid end of the secondary.

Connect a wire from the rotor, or movable plate, of the condenser, to the grid-return wire. Your hand will then have no effect on tuning when near or on the knob. Also connect a wire from the B-minus battery terminal to the ground. This often improves the operation of the set.

Wire the filament circuit. Connect a wire from the A-minus binding post to the other filament terminal (No. 8) on the tube socket.

Wire the plate circuit. Connect a wire from the plate (No. 2) terminal of the tube socket to one of the earphone binding posts. Run a wire from the other earphone post to the B-positive post. Connect a wire from the B-minus post to the A-positive post.

Here Are Some Wiring Hints

Soldering. Solder every joint except when the wire can be screwed down tightly under a binding post. Such wires should be scraped clean at the joint. Noisy set operation is usually caused by loose and unsoldered joints.

Neat Wiring Methods vs. "Haywire." Any sets that you build should be neatly wired, since you want to become familiar with the circuits and avoid mistakes in wiring. Fasten the wires to the baseboard with small staples, or solder them to the heads of small nails driven into the board.

How to Operate the Set

Step 1. Connect the antenna and ground lead-in wires to the antenna and ground posts on the set. The antenna lead-in wire must be insulated.

Step 2. (*a*) Put the 1LE3 tube in the socket. (*b*) Connect two insulated A-battery wires to the connectors on the set. (Attach these wires to the set first, so that if the bare wire ends touch, they will not short the A battery and ruin it.) (*c*) Connect the A-battery wires to a $1\frac{1}{2}$-volt dry cell. Be sure that the connections are correctly made.

Step 3. Connect the B battery and the earphones as follows: (*a*) Connect two insulated wires to the B-positive and B-negative posts on the set. Connect these wires to the set first to avoid shorting the B battery. (*b*) Connect the wires to a $22\frac{1}{2}$-volt B battery. Check to see that the positive and negative connections are correct. The set will work only when these connections are correctly made. (*c*) Put on the earphones. Connect one tip of the phone cord to the phone connection on the set. A loud noise will be heard in the phones when the other tip is touched to the connection. The filament must be heated, or no sound will be heard.

Operating Hints

The B battery will burn out the tube filament if it is connected across the A connections. This mistake is not likely to be made if the A battery is connected first.

Loose connections are noisy, since the resistance of the connections changes if the set or table is jarred. Small changes of resistance may be heard in the phones as a noise.

Tube sets are quiet either when all connections are soldered or when the wires are scraped clean and bright and then twisted tightly together for several turns. Soldered joints are preferable.

Why It Works

What is tuning? When you turn the tuning condenser of your receiving set, you adjust the timing of electron surges of alternating current in the tuning circuit.

You will now examine again the nature of an electron surge, and then you will learn about the action of these surges in the

tuning circuit as you move the dial to select a station. The tuning principle is used in some form in most radio circuits. To understand tuning, you must have a clear grasp of the way the back voltage of the coil is made to oppose the back voltage of the tuning condenser so that a strong current of the desired frequency will flow and currents of all other frequencies will be killed.

What have you learned about electron surges? You have learned that alternating current is a flow of free electrons—some moving away from the copper atoms of the wire conductor and others darting about in the space between atoms, but the mass flowing first in one direction and then the other through the wires. You have also learned that the rate at which the electron flow changes direction is called the frequency and that a flow in one direction and back is called one cycle. If you are tuned to a broadcasting station, your radio tuning circuits are adjusted for a frequency somewhere between ½ million and 1½ million cycles a second—1 million cycles, for example.

A surge starts when the current is turned on or is suddenly made stronger. But what is an electron surge? An electron surge is the effect that travels from atom to atom, among the flowing free electrons, and through the wire conductor at nearly the speed of light.

What is resonance? When you tune a set, you control the time it takes an electron surge to make a round trip through the tuning circuit. When you tune your set to receive the signals of a particular broadcasting station, you adjust the tuning circuit so that surges induced in it from that station meet a minimum of opposition. Then surges from other stations at other frequencies find so much opposition in the circuit that they either cannot flow at all or are so weak that they can be disregarded. Although an electron surge moves nearly at the speed of light, it takes a measurable amount of time to go from one end of the circuit to the other.

When you adjust the tuning condenser of your set to the frequency of a broadcasting station, you adjust the electrical length of the tuning circuit so that the surges go through it at the same rate that the surges do in the broadcasting transmitter circuit. Your circuit is then *tuned to resonance* with the frequency of this broadcasting station. At resonance the surges are correctly timed,

they meet little or no opposition, and a strong current flows. An example will help you to understand this principle.

If a radio station broadcasts on a frequency of 680 kilocycles (680,000 cycles per second), you know that there are 680,000 round-trip electron surges each second in its antenna when a program is being broadcast. When you adjust the tuning circuit of your receiver to this frequency, strong electron surges similar to those at the broadcast-station transmitter flow in your receiver. This is excellent, because you can then take energy from the tuning circuit to control the tube circuit so that you will hear the program in your earphones. This adjustment of the tuning circuit ensures that the signals from the station broadcasting on 680 kilocycles, and no other, get through to the tube circuit so that you hear the program in your earphones. Your receiver is now *tuned to resonance* with the incoming signal from this one station.

But if you adjust the electrical length of your circuit so that it is either too long or too short for the station frequency, your circuit will be out of resonance with this station, and, because the surges will be out of time, they will interfere with and kill each other. Then, since little or no current will flow in the tuning circuit to control the tube circuit, you will hear no program. Your set will be tuned *off resonance*.

PART 4: HOW WE SUMMARIZE THE TUNING PROCESS

Now suppose you go farther into the action of the tuning circuit. Follow the electron surges from the antenna into the tuning circuit. Although this whole process takes place smoothly and continuously, it is easier to study it as you would the frames of a motion-picture film, examining one frame at a time.

Frame 1. The current flows in the antenna-ground circuit. You already know how passing radio waves set up in your antenna a weak radio-frequency alternating current that surges from antenna to ground and back (see Fig. 158). You know that radio waves from each broadcasting station tries to set up a current in your antenna at its own frequency. (Each broadcasting station is tuned to a different frequency to prevent interference between stations.)

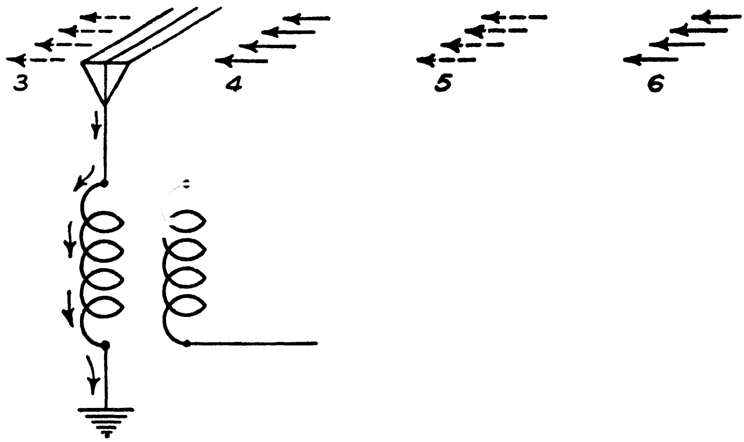


Fig. 158. *Frame 1.* A passing radio wave induces a current in the antenna-to-ground circuit.

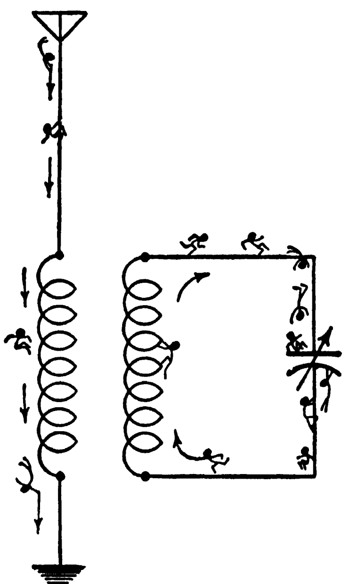


Fig. 159. *Frame 2.* A voltage is induced in the secondary coil. This voltage causes a current to flow in the opposite direction to the current in the antenna-to-ground circuit.

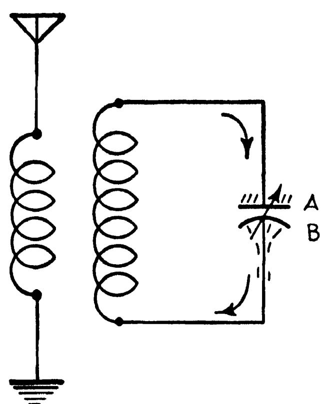


Fig. 160. *Frame 3.* The induced voltage begins to fill the plates on side *A* of the condenser with electrons. Electrons are also pulled off side *B*.

Frame 2. Voltage is induced in the secondary coil. The alternation of the current surging through the primary coil induces an alternating voltage, which sets up an alternating current, in the secondary coil (see Fig. 159). This current is in the opposite direction to that in the primary coil.

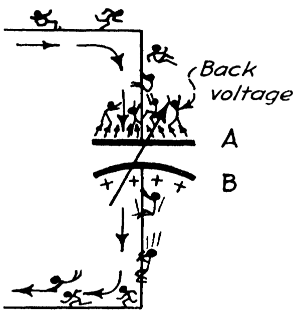


FIG. 161. *Frame 4.* As side *A* of the condenser fills with electrons, they set up a back voltage because they repel each other and they also repel other electrons trying to get on the plates.

Frame 3. Side A begins to fill with electrons. The induced voltage in the secondary coil drives electrons onto side *A* of the tuning condenser (see Fig. 160). The plates on side *A* begin to fill with electrons.

Frame 4. Back voltage builds up in the condenser. As side *A* of the condenser fills with electrons, they set up a back voltage which rapidly increases until it is strong enough to stop the flow of electrons onto this plate (see Fig. 161). The back voltage then tries to force electrons off side *A*.

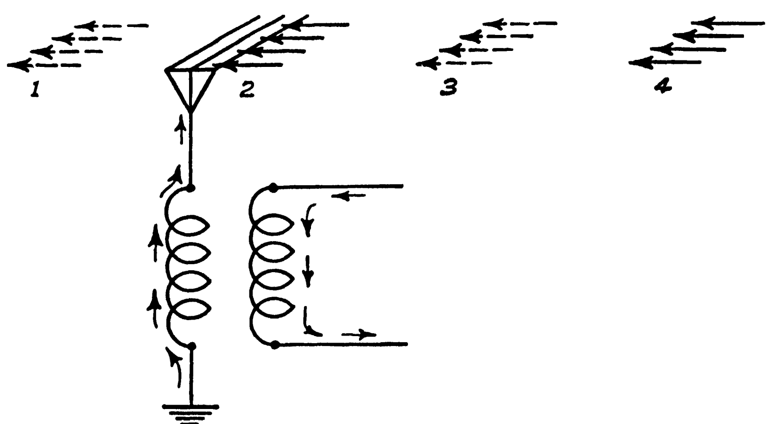


FIG. 162. *Frame 5.* When the next part of the radio wave strikes the antenna it starts a current flowing *upward* in the antenna-to-ground circuit.

If the condenser is properly adjusted, its maximum back voltage occurs just as the current in the antenna reverses. This proper adjustment occurs at resonance.

Frame 5. The current in the antenna reverses. As the next alternation of the radio wave flashes past the antenna, it sets up an electron surge *upward* in the antenna-ground circuit (see Fig. 162).

Frame 6. The electron flow in the coil reverses. The upward flow of current in the antenna induces a voltage in the secondary in the opposite direction (see Fig. 163). This pulls the electrons off side *A* and drives them through the coil onto side *B*. But suppose you examine the action of the condenser and coil more closely. Here is a close-up of the action.

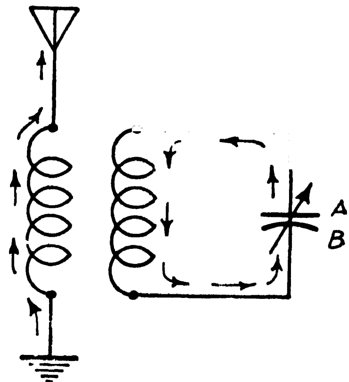


FIG. 163. *Frame 6.* The upward current flow in the antenna-to-ground circuit induces a voltage and current flow in the tuning circuit in the opposite direction.

Frame 7. The condenser helps the coil. When the induced current in the secondary starts its reverse surge, it sets up an opposing back voltage in the coil. The back voltage of the condenser pushes the surplus electrons off side *A* at the same instant that the induced voltage in the coil pulls them (see Fig. 164). The back voltage of the condenser at resonance is equal and opposite to the

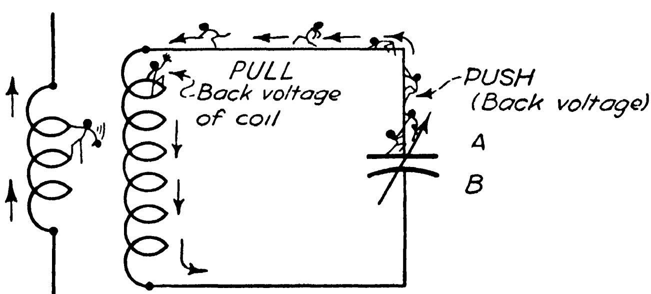


FIG. 164. *Frame 7.* When the reversing surge of electrons reaches the coil, it sets up in the coil an opposing back voltage. But, just this instant the back voltage of the condenser pushes out electrons and helps to overcome the back voltage of the coil.

back voltage of the coil. Now, with the back voltage canceled, the induced current can flow easily in the tuning circuit. This current will be strongest at resonance, a condition you want so

that you can get the loudest music from a fairly weak signal in the antenna circuit.

Frame 8. What happens at the end of the first surge? When the antenna current begins to weaken, the field around the secondary begins to collapse toward the end of a surge, and the helping back voltage of the coil produced by the collapsing field tries to keep the electron surge flowing and to force more electrons onto side *B* (see Fig. 165).

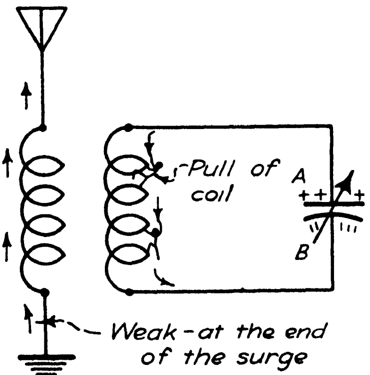


FIG. 165. *Frame 8.* When the antenna-to-ground current begins to weaken, the collapsing field around the secondary coil induces a current which tries to keep the surge flowing in the secondary and onto side *B* of the condenser.

This completes one cycle, or round-trip surge, through the tuning circuit. The complete round-trip surge is called *one oscillation* of current through the tuning circuit.

Why does a strong current flow at resonance? Now that you have studied how a complete surge moves through the tuning circuit, you can study the reasons why the circuit allows strong currents of one frequency to build up and why currents of other frequencies are killed.

At resonance, a strong current flows in the tuning circuit of your receiver, because the condenser is set so that it becomes filled with electrons and sets up a back voltage just as the surge reverses in the secondary coil. When the reverse current starts to flow, the back voltage of the coil opposes it. But the back voltage of the condenser, which you make equal to the back voltage of the coil when you tune the circuit, cancels the back voltage of the coil. The induced current surges can then flow through the tuning circuit with no opposition from the back voltage of either the coil or the condenser.

When you tune the set, you adjust the condenser so that the two back voltages are exactly equal and opposite. They then cancel each other and the current surges set up in the coil from the antenna flow easily. You hear the station to which you are tuned most loudly at this adjustment of the tuning condenser.

The resistance of the circuit then is the only thing that restricts the loudness of the sound you hear in your earphones.

What happens when you tune to resonance? Remember that the impedance in any circuit consists of both the back-voltage effect (reactance) and resistance. When you tune your receiver to resonance, the back voltages are canceled and only the resistances of the coil wire, of the wire joints, and of the metal in the condenser plates hinder the surging of electrons through the circuit. Radio engineers design coils that offer minimum resistance to current flow. They plan their connections and design their condensers for low energy loss. All joints in the circuit wiring should be carefully soldered to keep down resistance and reduce energy loss.

Now, with the circuit offering only a small amount of resistance to current flow, the current surges build up and reach their greatest strength, so that the voltage delivered to the tube circuit will be large.

What happens when you tune off resonance? When you tune "off resonance," back voltage kills the signals from stations you do not want to hear. How does this happen?

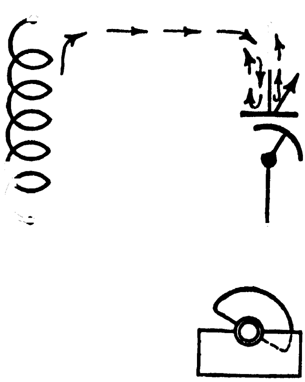


FIG. 166. When tuned off resonance, the back voltage of the condenser either seriously weakens the surges in the secondary or kills them.

When you set the condenser at too small a capacity for the current surges of signals from an unwanted station, the condenser fills with electrons before the completion of a surge in the coil. The condenser back voltage builds up while electrons still are being driven toward the condenser from the coil.

The back voltage from the condenser then is strong enough to oppose the induced voltage caused by the unwanted signal and either reduces its strength or kills it completely (see Fig. 166). In an efficient receiver you can completely kill signals from an unwanted station. You say that you "tune out" the unwanted station. The sharpness of the tuning, which is represented by the amount you must turn the tuning dial to tune in one station and tune out another, largely depends on the resist-

ance of the circuit. This resistance reduces the strength of the signal and also spreads out the tuning across the dial.

How does the condenser setting affect frequency? When you turn the tuning dial, you move the condenser plates. At each different setting of the plates, the tuning circuit will respond to a different frequency. Figure 167 illustrates a circuit in which the plates of the condenser are out of mesh, so that small plate areas are opposite each other. The capacity for this setting is low, and the condenser fills with electrons and empties rapidly. The circuit will then tune to a *higher* frequency. The surges come and go more rapidly.

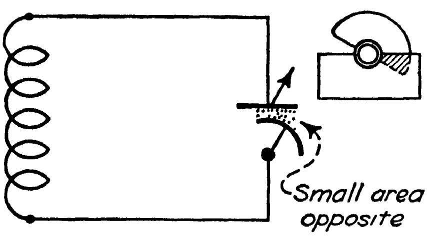


FIG. 167. When the condenser is set with the plates out of mesh, only a small area of the plates is opposite to each other, and the plates fill and empty rapidly. The condenser now tunes to a high frequency.

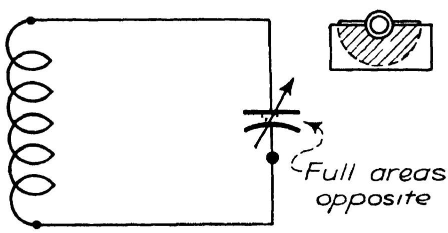


FIG. 168. When the plates are fully meshed, there is more capacity in the circuit and the plates fill and empty more slowly. Now the circuit tunes to a lower frequency.

But in the circuit shown in Fig. 168, the condenser has more capacity and takes longer to fill and empty. The surges through the circuit take a longer time, and the circuit tunes to a *lower* frequency.

PART 5: HOW COUPLING AFFECTS TUNING

You can further improve tuning by changing the spacing, or coupling, between the primary and the secondary coils of the receiving transformer. Years ago it was customary to arrange the secondary coil to slide in and out of the primary in order to change the coupling between the two coils. When the two coils were close together, they were said to be *closely coupled.* The coils were kept closely coupled so that the signals heard would be as loud as possible. If, however, unwanted signals were heard. the coils could be slid apart to loosen the coupling. Loosening

the coupling helps the circuit to keep out unwanted signals. An experiment will show this effect.

Loose and Close Coupling Experiment

Step 1. Wind a coil of 30 turns on a form that will slip over the transformer used in the last experiment (see Fig. 169).

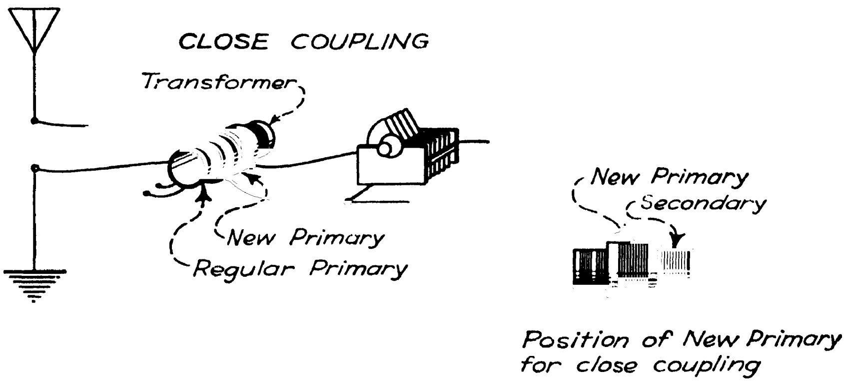


FIG. 169. A separate primary is used to demonstrate coupling. Here it is set for close coupling. Signals are loud but tuning is poor.

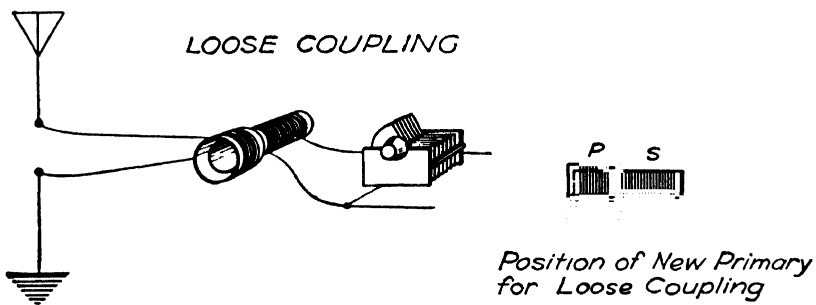


FIG. 170. When the sliding primary is set as shown here the coupling is loose. Signals are now weaker but unwanted stations can be tuned out.

Step 2. Attach the antenna and ground wires to the new coil. Make no connection to the old primary coil.

Step 3. Set the new coil at about the center of the secondary (see Fig. 169).

Note two things about signals from a strong and from a weak station: (1) The loudness of the signal and (2) how easily you can tune it out.

Step 4. Move the new primary toward the end of the secondary (see Fig. 170). Again tune and note both loudness and sharpness of tuning.

Step 5. Move the primary to a position where you can tune sharply and still get fairly strong signals.

Why It Works

You soon find that, when the secondary is loosely coupled, the signals, while somewhat weaker, can be more sharply tuned and unwanted stations can be tuned out.

The secondary coil and the condenser each set up different amounts of back voltage to signals from different stations. At resonance, as you have just learned, the back voltages produced by the signal from the station you wish to hear cancel each other, and a strong current builds up in the coil. The program comes in as loudly as possible. But to tune off resonance to eliminate this station, you adjust the tuning circuit so that the back voltages fail to cancel, and little or no current at the station frequency flows in the tuning circuit. This is how you tune out unwanted stations.

However, you found that, when the primary and secondary were quite close together or closely coupled, signals from a strong station could induce currents in the secondary strong enough to force their way through the circuit, in spite of the back voltages of coil and condenser.

By sliding the coils apart to loosen the coupling, you found a position, or amount of coupling, at which the signals from the strong station were weakened. At this loose coupling, you can tune out strong stations and you can also hear weaker stations. The weak stations may not be as loud as you would like, but they are clear and free from interference from other stations.

To be forced to make coupling adjustments whenever you tune your set is such a nuisance that coils are now wound a small distance apart on the coil form, so that they are loosely coupled. The coupling adjustment is thus discarded. Efficient modern tubes and amplifying circuits more than make up for any loss in signal strength caused by fixed coupling.

Questions

1. What is an electron surge?
2. What is a cycle?

3. Why are off-resonance stations not heard well when you tune the set to resonance for a given frequency?

4. Compare the number of surges per second in the tuning circuit of your set with the number of surges in the tuning circuit of the transmitter with which you are tuned to resonance.

5. Describe in detail what happens when you set the condenser of your set at too great a capacity for the current surges from an unwanted station.

6. Why do not modern sets still have the tuning-coil secondary, so that it can be slid in and out of the primary coil?

7. What effect has loose coupling on the signal strength?

8. Can your set be more sharply tuned with close or with loose coupling?

Technical Terms

coupling—The transfer of energy between the primary and secondary of a tuning circuit.

resonance—The result of your tuning circuit's electrical length being such that the electron surges go from end to end at the same rate as they do in the tuning circuit of the broadcast transmitter. Your set is then said to be in resonance with that station. Resonance occurs when the back voltage, or reactance, of the coil and of the condenser in the tuning circuit are equal and opposite.

tuning—Adjusting your set so that you can hear one station and exclude all others.

CHAPTER 12

RECEIVING SETS USING DIRECT-CURRENT TUBES

Although making your first one-tube receiving set was a thrilling experience, you soon find that the set is so limited in range that it will bring in only a few stations. If you are like other radio experimenters, you want to show it off to your friends, but this is hard to do unless you are able to attach a loudspeaker to the set instead of earphones. A one-tube set has insufficient power to operate a speaker, but you can quite easily build an amplifier to attach to it; it will bring in stations that were too weak to hear before and amplify, or strengthen, the music you could already pick up until you can use a loudspeaker. Then your friends can enjoy the set with you.

In this chapter you will study several kinds of circuits that can be used to make your one-tube receiver more efficient. You will build two types of amplifiers: the radio-frequency amplifier, which makes your set more sensitive, and the audio amplifier, which increases the volume, or loudness, of the music.

You will study both types of amplifiers, using the simpler three-element tubes, while you are learning the principles upon which the amplifiers operate. In later chapters you will use sensitive multi-element (multi-element) tubes, which allow you to do things with the amplifiers not possible with the simpler tubes.

You will learn the following things in this chapter:

Part 1: How a Complete One-tube Receiving Set Works
Part 2: How the Grid-condenser Grid-leak Detector Circuit Works
Part 3: How to Build the Regenerative Receiver
Part 4: Kinds of Audio-frequency Amplifying Circuits
Part 5: How to Build a Transformer-coupled Audio-frequency Amplifier
Part 6: How to Build a Resistance-coupled Audio Amplifier
Part 7: How to Build a Power Audio Amplifier

PART 1: HOW A COMPLETE ONE-TUBE RECEIVING SET WORKS

In the chapter on resonance and tuning which you have just completed, you learned how the tuning circuit operates and the theory of its action. Your study was limited to the tuning part of the circuit. Perhaps you wondered why so much attention was focused on this part of the circuit and why the relatively strong surges of alternating current were able to build up in the tuning circuit and produce sound in the earphones.

Now let us continue this study to see how part of the energy in the tuning circuit is directed to the vacuum tube, how it causes

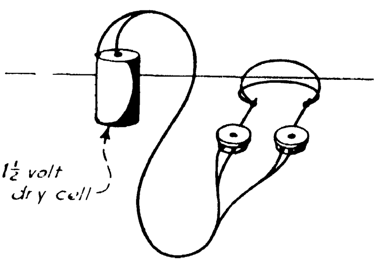


FIG. 171. Touch the tips of the earphone cord to the dry cell terminals. You hear sound when the diaphragms of the earphones move.

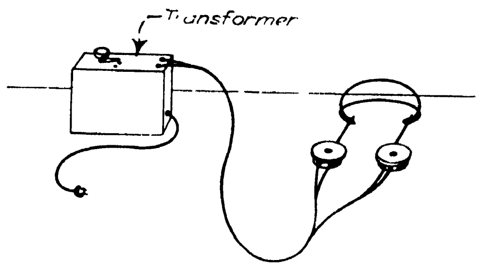


FIG. 172. Touch the earphone cord tips to the transformer terminals and you hear a steady hum because the steadily changing strength of the alternating current vibrates the diaphragms.

the tube to control the current that flows in the earphones, and how sound is produced.

You will find it profitable to read again the description of earphones in Chapter 9.

How is sound produced? Sound is produced in the earphones when the current flowing through their coils changes in strength (becomes stronger or weaker). You can easily show this effect by touching the tips of an earphone cord to a 1½-volt dry cell (see Fig. 171). You will hear a sound twice: when you touch the tips to the battery and when you remove them. The first sound is caused by the diaphragms being sharply pulled inward or pushed outward, depending on the direction of the current flow. The second sound is caused by the movement of the diaphragms as they return to rest. You hear *no* sound when a *steady* current

flows through the earphones, because the diaphragms are then held in one position.

Now connect the phones to a small step-down transformer and adjust it to deliver about 6 volts (see Fig. 172). You hear a steady hum, because the rapidly alternating current moves the diaphragms back and forth each time the current reverses.

If you connect earphones to the tuning circuit, as in Fig. 173, you hear no music, because the alternating-current surges that flow in the tuning circuit have a frequency far above your hearing range. They change direction about a million times per second,

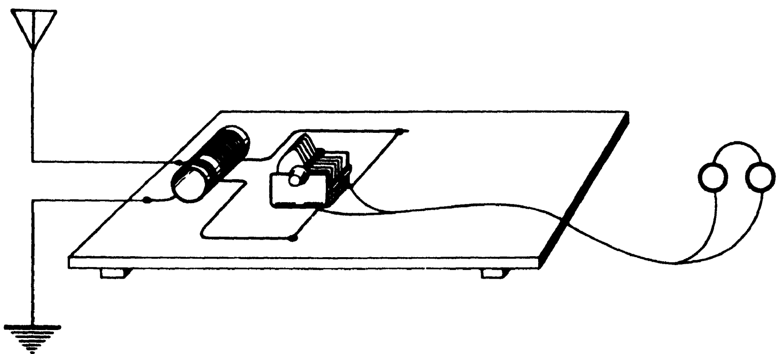


FIG. 173. You will hear no sound with this connection because the current changes occur at radio frequency (millions of times a second), which is far above your hearing range (16,000 cycles a second).

their rate being the same as the frequency of the broadcasting transmitter.

You can hear sound produced by motions of the earphone diaphragms only up to about 16,000 times per second. So, even if the diaphragms could move rapidly enough to respond to the current surges in the tuning circuit, you would still be unable to hear sound. But there is a way to bunch these radio-frequency surges in the tuning circuit into groups so that they will produce sounds in the earphones. For example, let us try the following experiment:

Experiment. Connect the tuning circuit to the tube circuit. Connect the grid wire to the stator of the tuning condenser (see Fig. 174). When the current in the tuning circuit in Fig. 175 surges toward side *A* of the condenser, it will drive electrons onto the grid of the tube. These surplus electrons on the grid make it negative. You learned in an earlier chapter that electrons on the

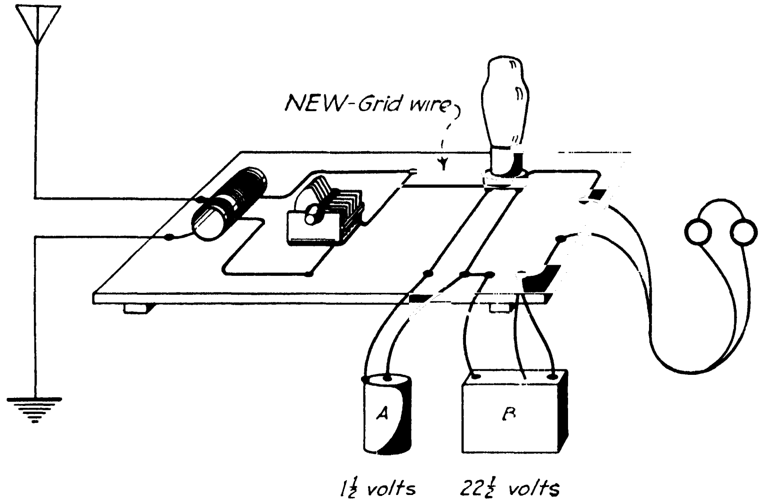


FIG. 174. Connect a wire from the stator side of the tuning condenser to the grid terminal of the tube socket.

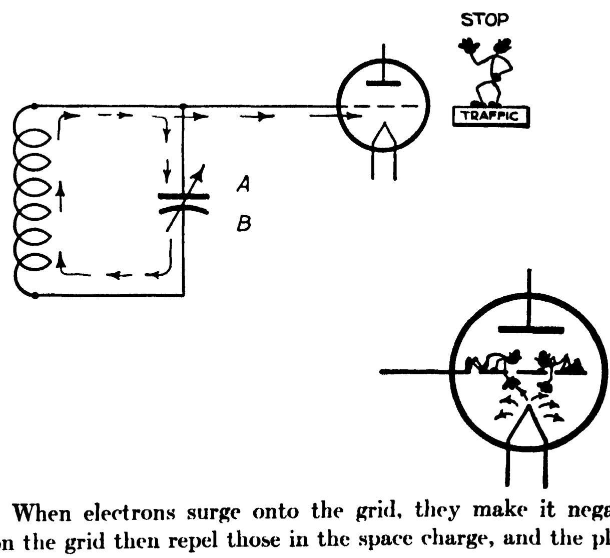


FIG. 175. When electrons surge onto the grid, they make it negative. The electrons on the grid then repel those in the space charge, and the plate current becomes weaker.

grid act like a traffic cop: they make the voltage between the grid and the filament more negative and give the stop signal to the flow of electrons from the space charge to the plate.

Rule. When the grid is made more negative (or less positive) it repels the electrons in the space charge and weakens the current flowing through the tube.

Then, when the current in the tuning circuit surges in the other direction, as in Fig. 176, it draws electrons off the grid and makes the grid less negative, and the traffic cop gives the go signal to the electrons in the space charge.

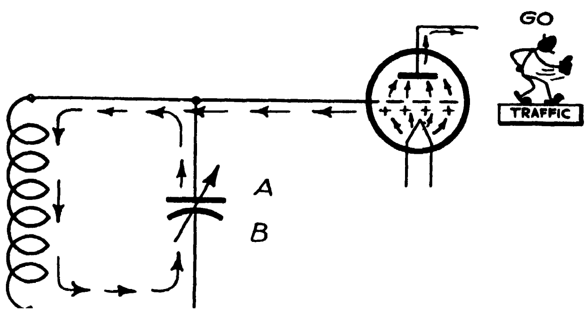


FIG. 176. The grid becomes positive when the surge swings toward side *B* in the tuning circuit. The positive grid attracts electrons from the space charge and the plate current becomes stronger.

But when the grid is less negative, unlike the traffic cop, it decreases its repelling action on the electrons surging toward the plate and the plate current becomes stronger.

Rule. When the grid is made less negative (or more positive), its repelling action on electrons flying toward the plate is reduced, so that more current flows through the tube than before.

Connect a grid-return wire. You will need a wire from the rotor side of the condenser to the filament, or B-negative, side of the tube circuit (see Figs. 177 and 178). This is now the same set you used in Chapter 11 for variable-condenser tuning. If this wire is left off, the set will not play well; it may not even play at all. But why?

Every other surge in the tuning circuit makes the grid more positive. When more positive, it attracts a few electrons from the space charge. If no electrons could leave the cold grid, the grid would soon become crowded with electrons that it had col-

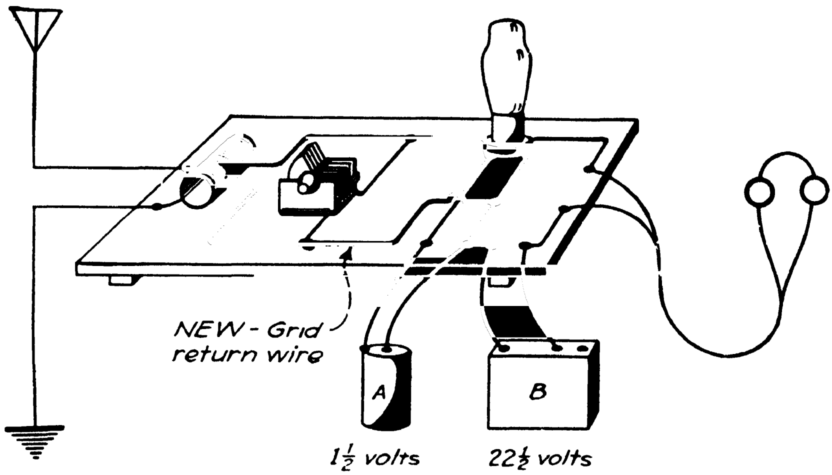


FIG. 177. This is the escape path for electrons that would otherwise be collected on the grid by each positive surge and trapped there. Instead, they use the *grid return* path to escape back to the filament circuit out of the way of other surges on the grid.

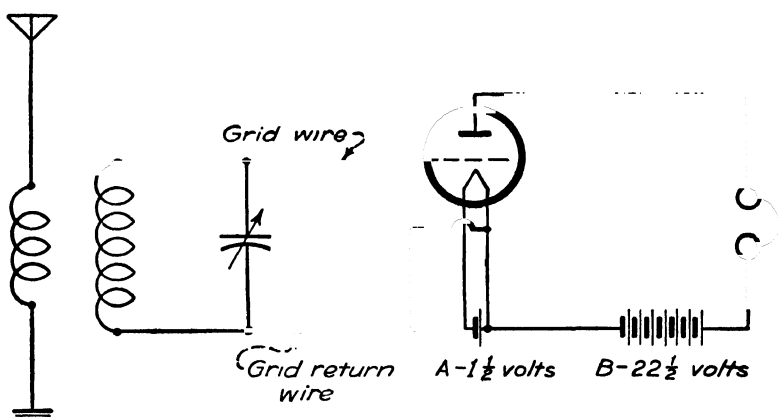


FIG. 178. This is the schematic circuit diagram of the one-tube receiving set shown in Figs. 156 and 157.

lected. They would make the grid so negative that no current could flow through the tube, and, consequently, no sound would be heard.

When you attach the *grid-return wire*, these extra electrons can escape from the grid and return to the filament through the coil.

How does the tube circuit use the surges to produce sound? But how does a weak radio-frequency current surge in the tuning circuit, which drives electrons on and off the grid, cause the earphones to move so that you hear music or a program?

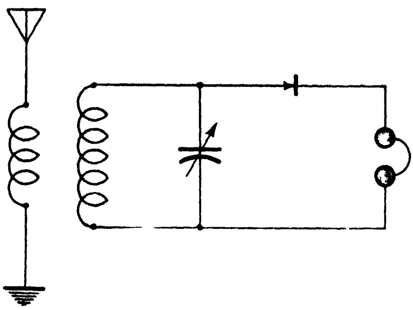


FIG. 179. This is the schematic circuit diagram of the crystal-detector circuit. The weak current in this circuit moves the diaphragms of the earphones. The sound is weak.

Compare the weak music, or program, that you hear on a crystal-detector set with the louder sound you hear from the one-tube detector set. The power from the B battery and the amplifying action of the tube are the reasons for this increase in the music's volume.

In the crystal receiver the current surges induced by the antenna in the tuning circuit actually flow through the earphones to produce the sound you hear (see Fig. 179). This current is necessarily weak. But in the tube circuit (see Fig. 180) the current surges in the tuning circuit have an entirely different job to do.

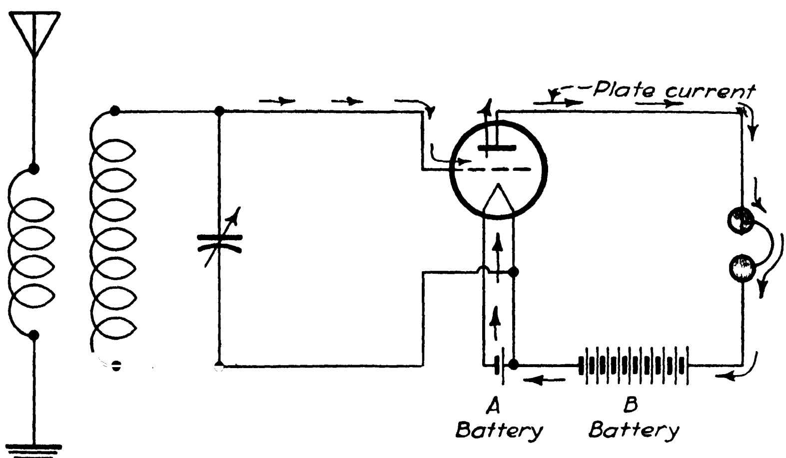


FIG. 180. The weak tuning circuit surges *control* the strong current in the plate circuit. The grid acts as a sort of electrical lever. The music is louder than when a crystal detector is used.

They make electrons flow on and off the grid and so act as a *control voltage;* the current surges do not flow in the earphones.

Rule. The current surges in the tuning circuit act on the grid and control the strength of the plate current.

The voltage driving electrons back and forth in the tuning circuit is relatively weak. The voltage forcing the current to flow in the plate circuit, from the B battery through the tube, is relatively strong. In this experiment you use the vacuum tube as a sort of electrical lever, where a weak voltage, or pressure, driving electrons on or off the grid controls the strength of a powerful current (see Fig. 180). The strong plate current flowing through the earphones now follows the variations of voltage and current in the tuning circuit. These changes of current strength produce loud signals in the earphones.

How do radio-frequency surges on the grid make audio-frequency surges in the earphones? We know that there are about 1000 radio-frequency surges to every single surge of a sound wave entering the microphone at the broadcasting studio. (We are assuming that the frequency of the broadcasting transmitter is 1,000,000 cycles, or 1000 kilocycles, per second and that the sound wave is at a frequency of 1000 cycles per second. Thus there are 1000 radio-frequency surges to each sound surge.) There are also about a million radio-frequency surges per second in the tuning circuit and on the grid of the 1LE3 tube in your receiver. These rapid surges on the grid make the plate current change in strength around a million times per second. But the earphone diaphragms are so heavy that they cannot move this fast. The plate-current surges are so fast and are of such short duration that no single surge will move the diaphragms (see Fig. 181).

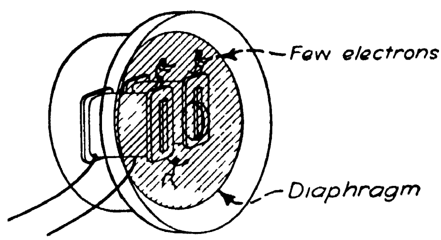


FIG. 181. The few electrons in each radio-frequency surge have too little strength to move the diaphragm.

When the tube acts as a detector, the voltage on its elements is arranged so that the signals on the grid produce an uneven plate-current change. An example will help you to see this. Suppose that a 1-volt signal reaches the grid. This makes the grid 1 volt

positive and then 1 volt negative. The detector plate current would increase approximately 2 milliamperes when the grid was 1 volt positive. But when the grid becomes 1 volt negative, the plate current would only decrease ½ milliampere.

The result of the increased current would pull in the earphone diaphragm. The reduced plate current would release it. But the pull inward is greater than the outward motion. This uneven pull on the diaphragm, with greater motion inward than outward, will produce music or other sound.

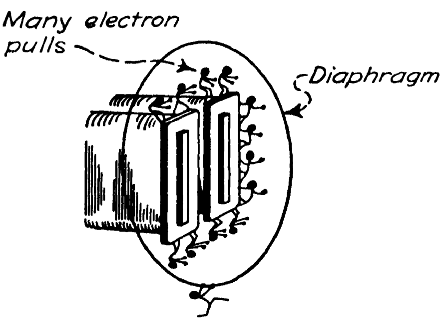


FIG. 182. When 1000 radio-frequency surges get together, their tiny pulls add and they easily move the diaphragm.

You will learn later how the proper voltage on the grid can cause the same tube to act either as a detector or as an amplifier. The back voltage of the earphone coils and the condenser effect of the phone cord blend the pull of each 1000 radio-frequency surges, so that a single little pull is accumulated from each surge. The accumulated pull of 1000 radio-frequency surges makes single motions of the diaphragms upward or downward (see Fig. 182). The blended pulls move the earphone diaphragms at a rate slow enough so that you hear sound.

In Fig. 183 you can see a summary diagram showing the way the energy which reaches your antenna from the broadcasting transmitter travels through the tuning circuit and the tube and makes your earphones produce sound waves.

This is the complete receiving process, using the tuning circuit and the vacuum tube in their simplest forms.

Now study a number of different circuits that you can use to make the simple receiver more sensitive, so that you can eventually operate a loudspeaker.

Questions

1. Will you hear a hum only when an alternating current or a steady direct current flows through the earphones?

2. If the earphones were attached directly to the tuning circuit, could you hear music? Explain.

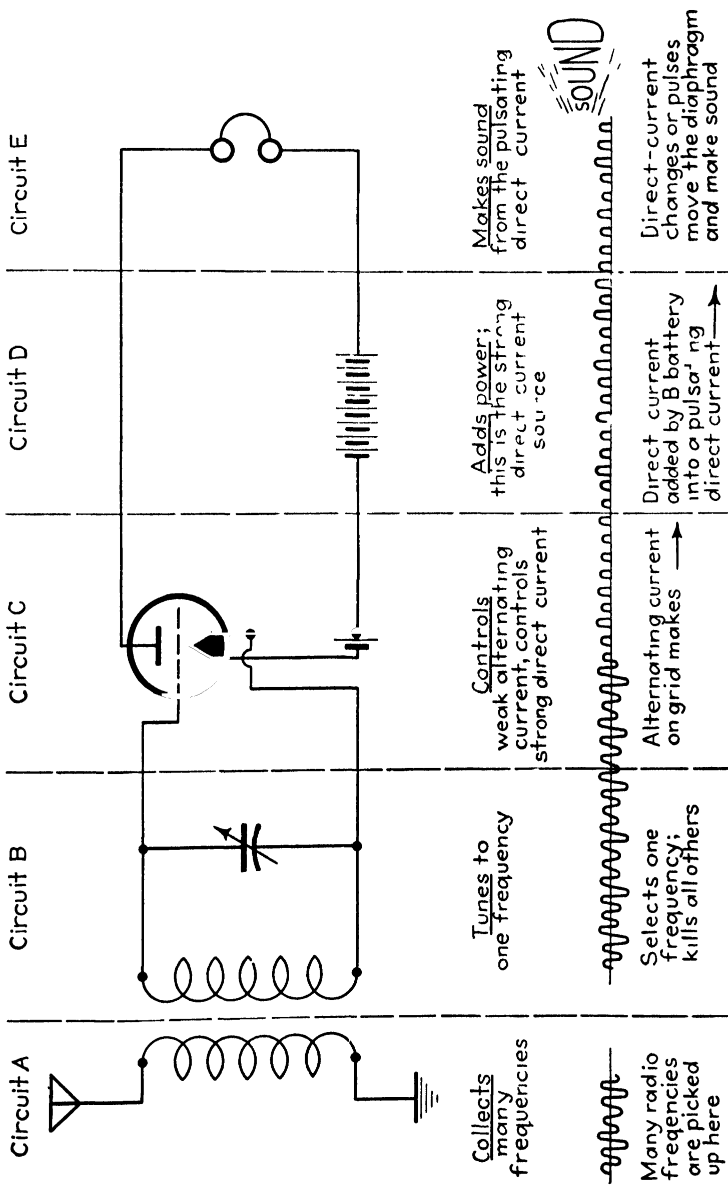


FIG. 183. This diagram shows the purpose of each section of the receiving circuit.

3. Does a negative grid weaken or strengthen the plate current?
4. Why will not the set play when you leave off the grid-return wire?
5. Why does not the diaphragm spring back after each radio-frequency surge?

PART 2: HOW THE GRID-CONDENSER GRID-LEAK DETECTOR CIRCUIT WORKS

A simple way to increase the efficiency of your one-tube detector set is to wire two small new parts in the grid lead. These parts are a 0.00025-microfarad (250-micromicrofarad) fixed condenser and a high resistance of about 2 million ohms (2 megohms) called the *grid leak*. When you wire these two parts, as shown in Fig. 184, you will be surprised at how much more sensitive your set becomes. You will be able to hear stations you were unable to hear before, and you will also find that stations you heard before are now louder. Hook up this set, and become acquainted with its action.

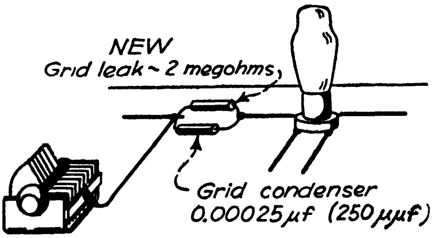


FIG. 184. Add the *grid condenser* and the *grid leak* to your one-tube receiver, and the set becomes more sensitive. Two clips mounted on the set board are used so that you can try different sizes of condensers and leaks.

How to Wire the Set

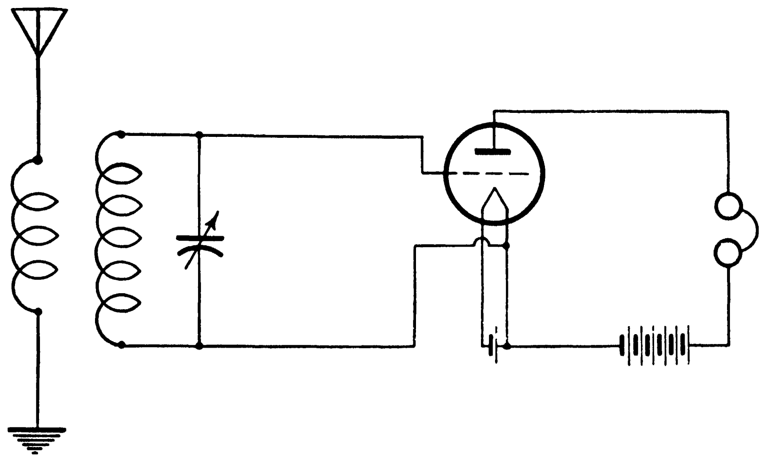
The Circuit. This circuit and set board is the same as the one-tube detector set (see Figs. 156, 157, and 185).

The Changes. Cut the wire between the secondary and G post of the tube socket, and mount two double Fahnestock clips for the 250-micromicrofarad grid condenser and the 2-megohm grid leak (see Fig. 184).

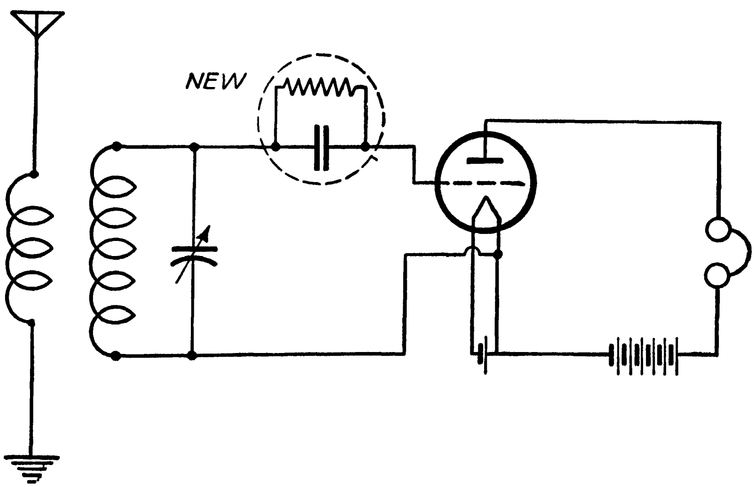
How to Operate It

Operate this set as you did the one-tube detector. Simply tune in the station you want to hear. The new parts make no change in the method of tuning.

Try several values of grid leaks until you find the one that works best. The best one will have a value somewhere between 1 and 5 megohms.



OLD CIRCUIT



NEW CIRCUIT

FIG. 185. The old and the new one-tube detector circuits with the grid condenser and the grid leak added in the lower diagram.

How It Works

Review "How is sound produced?" When surges from the tuning circuit force free electrons onto the grid or pull them off it, the plate current becomes alternately weaker and stronger. As the strength of the plate current changes, the diaphragms of the earphones move and produce sound. The sound will be louder if

you can find some way to make greater changes in the strength of the plate current when a given voltage is on the grid.

Suppose the positive part of the signal from Station *A* changes the grid voltage enough to cause the plate current to increase $\frac{1}{4}$ milliampere and the negative part changes it enough to decrease the plate current by $\frac{1}{4}$ milliampere. This $\frac{1}{2}$-milliampere change in current strength from the no-signal current produces the music you hear in the earphones.

If you can make the plate-current strength change by 2 milliamperes instead of $\frac{1}{2}$ milliampere, the music from this station will

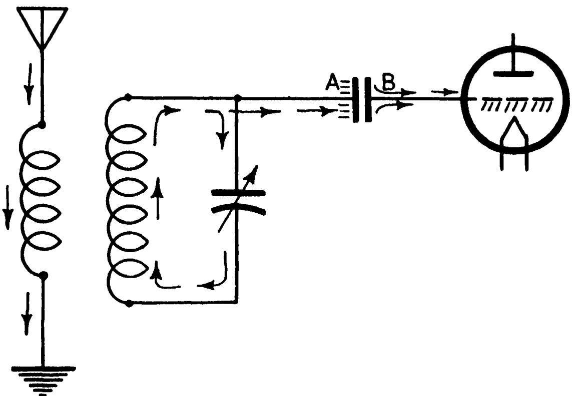


Fig. 186. When the surges in the tuning circuit drive electrons *on* the grid condenser, side *A*, others are forced off side *B* to the grid. This makes the grid negative.

sound louder, because the earphone diaphragms will move a greater distance than before. The grid-condenser grid-leak circuit produces such an effect.

How does the grid-condenser grid-leak circuit strengthen the music? The grid condenser acts like a reservoir, and the grid leak acts like an overflow relief valve. The condenser collects a few electrons from each radio-frequency surge in the tuning circuit until enough are collected to make a large reduction in the plate current. The grid leak prevents too many electrons from being stored up. Let us see how this is accomplished.

One surge drives electrons onto the grid. When the electrons flow downward in the antenna, electrons move through the tuning circuit, as shown by the arrows in Fig. 186. Some of these elec-

trons will flow onto the tuning condenser. The pressure of electrons on the tuning condenser forces some electrons on the grid

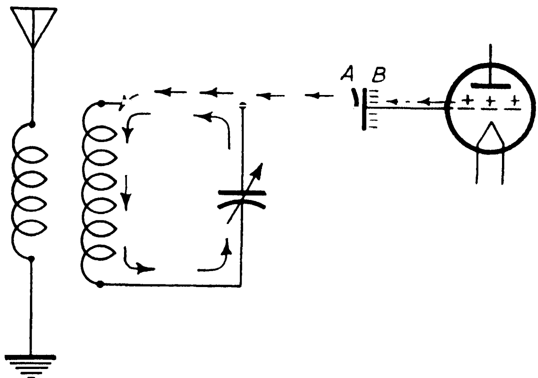


FIG. 187. When the tuning circuit surge reverses, it draws electrons *off* side *A*, which in turn draws electrons *off* the grid. This makes the grid positive.

condenser. Electrons on plate *A* of the grid condenser repel electrons on *B* and drive them to the grid, making it negative.

The next surge pulls electrons off the grid. When the current reverses and draws electrons off side *A* of the grid condenser, side *A* becomes positive. Electrons are drawn to side *B from the grid* (see Fig. 187). The grid, which then has fewer free electrons, becomes positive. But now a new action occurs.

The grid collects electrons from the space charge. When the free electrons were drawn from it, the grid became positive. The grid, when positive, acts like a small plate and picks up a few electrons from the space charge (see Fig. 188).

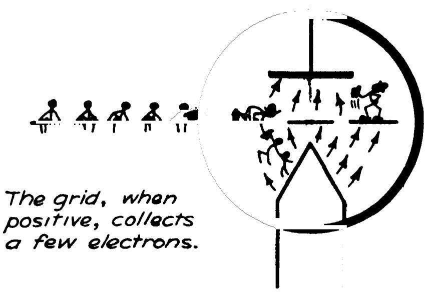


FIG. 188. No electrons can escape from a cold grid. But when the grid is *positive*, it pulls in some electrons from the space charge. The grid acts like a small plate with a weak pull.

These electrons collect on the grid and on plate *B* of the grid condenser, which acts like a reservoir.

Where are the collected electrons stored? The electrons on side *B* of the grid condenser are trapped (see Fig. 189). They

cannot get to side A, because the insulation between the plates of the grid condenser stops them.

The grid-condenser reservoir receives a few electrons from the space charge each time the grid becomes positive. These elec-

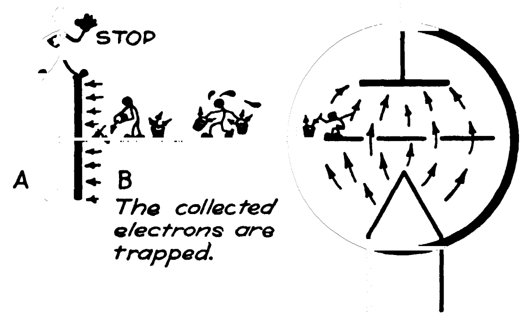


FIG. 189. Every time the grid goes positive, it collects a few electrons from the space charge around the filament. These electrons collect on the grid condenser, side B, because they cannot get through the insulation between the two plates to reach side A.

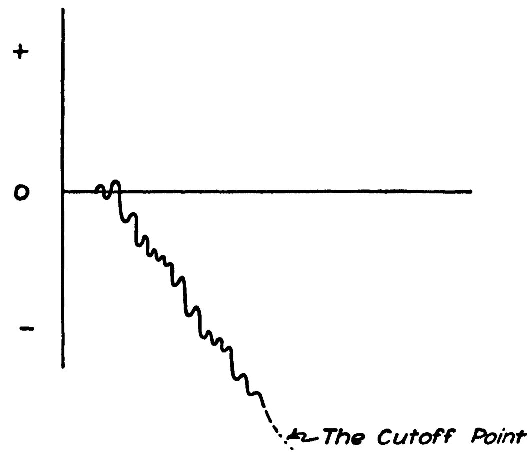


FIG. 190. As the grid becomes more negative, it gradually cuts off the flow of plate current. The grid voltage at which the plate current flow is stopped is called the *cutoff point.*

trons cannot escape from the grid back into the tube, because the grid is cold and cannot give up electrons. Inasmuch as there are about a million surges per second, it is easy to see how this process rapidly fills the reservoir.

What is the effect of the condenser on the plate current? As the grid continues to pick up electrons from the space charge, both side *B* and the grid become loaded with surplus free electrons. These electrons repel each other, a voltage builds up, and the grid becomes increasingly negative (see the wave pictures in Fig. 190). As the grid becomes more negative, it gradually cuts off the flow of plate current. It finally becomes negative enough to stop completely the flow of plate current from filament to plate. This is called the *cutoff point*. Now you will hear no music at all. Some way must be found to take care of the surplus electrons.

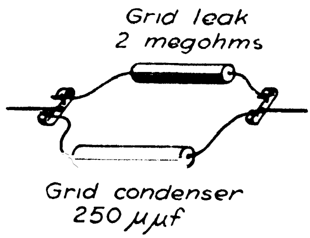


FIG. 191. The grid leak is connected in *shunt* or parallel across the grid condenser.

What is the action of the grid leak? The grid leak is the automatic release valve which allows the grid-condenser reservoir to collect enough electrons to make louder music, but which spills over before the plate current is stopped.

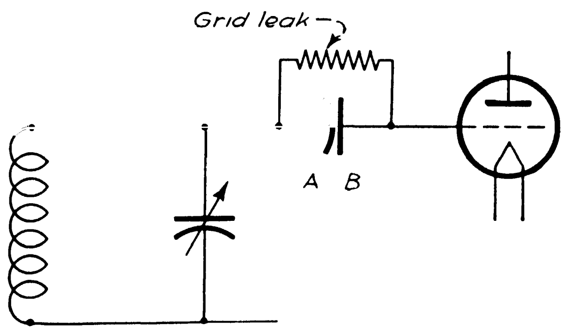


FIG. 192. This schematic diagram shows the grid-condenser storehouse with its grid-leak safety valve connected in shunt across the condenser.

The grid leak is a small pressed-carbon resistor which generally has a resistance between ¼ megohm and 5 megohms. (1,000,000 ohms equal 1 megohm.) It is connected in parallel with the grid condenser, as shown in Figs. 191 and 192. You select a leak with high enough resistance to hold electrons collected on plate *B*, so that the music will be loud, but the leak must still allow the set to play. When electrons accumulate on plate *B*, a voltage is built

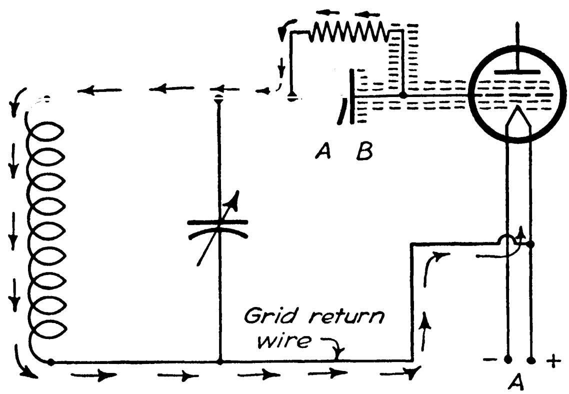


FIG. 193. This schematic diagram shows how the piled-up electrons force their way through the high resistance of the grid-leak safety valve. Trace their path around through the coil and back to the filament via the grid-return wire.

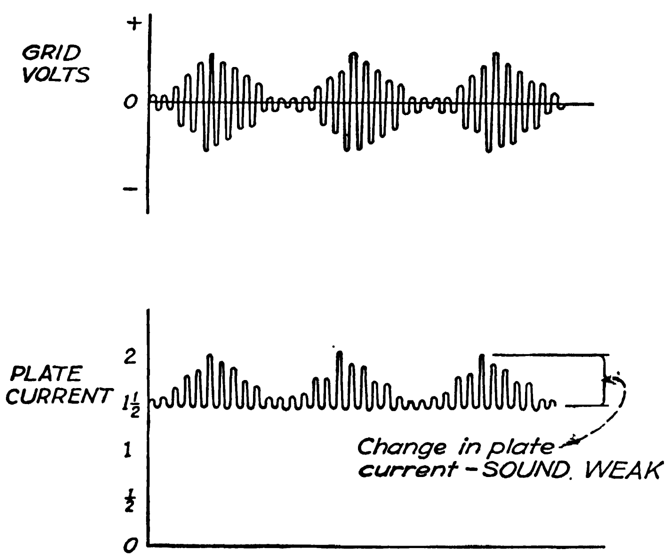


FIG. 194. The upper wave picture shows the pressure of electrons on the grid. The lower picture shows how the plate current rises and drops as the grid goes negative and positive. Note the small *change* in the strength of the plate current. The sound in the earphones is now weak.

up which forces an increased number of electrons through the high resistance of the grid leak (see Fig. 193). They flow through the coil and the grid-return wire to the positive side of the circuit and return again to the filament.

How does the grid condenser affect the plate current? The reason you wanted the grid condenser and grid leak in this circuit, as you recall, was to make the music louder. As the grid condenser, acting as a reservoir, stores a few more electrons each time the grid goes positive, it rapidly becomes crowded with free electrons, and because the grid is attached directly to it, the grid becomes more and more negative.

The current from the antenna is often called the *signal*. You say here that no signal is on the grid.

When a signal comes from the antenna, the group of surges of which it is composed starts the process that makes the grid become more negative. As the grid becomes more negative, it reduces the plate current further and further. Near the end of the group, the grid leak allows the electrons to flow off. Figure 194 shows the wave picture when no grid condenser and grid leak were used.

You can see that the grid-condenser grid-leak circuit makes a much greater change in the plate current than the original circuit did. Since it is the change of plate current that produces sound, the diaphragms of the earphones move farther, and louder sound is produced.

Questions

1. What is the purpose of the grid leak?
2. What is the purpose of the grid condenser?
3. Would a set work satisfactorily with either a grid leak or a grid condenser alone? Explain.
4. How many ohms resistance has a grid leak?

PART 3: HOW TO BUILD THE REGENERATIVE RECEIVER

One of the fascinating things about radio has been the constant search for ways to bring in stations more loudly and the attempts of the "DX hounds" who spend hours searching the air to hear distant stations. These experimenters try trick circuits, odd and amazing coils and condensers, anything in their attempt to reach beyond into the elusive distance (DX).

While still a student, E. H. Armstrong, the brilliant American

inventor, reasoned that some way could be found to add power from the B battery to increase the power input to the set from the weak signals from the antenna. This would put stronger signals on the grid and would make louder sounds in the earphones. He worked out the regenerative receiver to do just this. He obtained a very sensitive receiver, one that reached out and brought in faint, distant signals that he had not even been able to hear with other one-tube sets.

Regeneration is a form of amplification. When you use the regenerative circuit, your detector set will be about as effective as if you had added two stages of radio-frequency amplification; yet you will not have the expense of adding tubes and other apparatus needed in the amplifier.

The most important feature about the regenerative set is that it will respond to extremely weak signals. Regenerative receivers once were widely used by amateurs in short-wave work because of their simplicity. Advanced amateurs, however, often use more complicated and expensive types of receivers.

How to Build the Set

Use the one-tube set board. The baseboard of the one-tube receiving set is designed for several receiving circuits. Wind a new coil and add a variable resistor at the right of the board between the B positive and the nearer of the earphone binding posts. See Fig. 195 for the arrangement of the parts. The dotted line shows the position of the shield plate mentioned in "How to Operate the Set."

Wind a new receiving coil. Use a 2-inch Bakelite or pasteboard tube.

The Windings. Wind three coils on the tube for the regenerative circuit.

The Wire to Use. Use wire between No. 22 and No. 28 for the three coils. The larger sizes are preferable. The insulation may be cotton, silk, or enamel. A shorter tube will be needed if the wire is smaller than No. 22.

The Primary, or Antenna, Coil. Wind 15 turns of No. 22 wire. Start $\frac{3}{8}$ inches from one end of the tube.

The Secondary, or Grid, Coil. Wind 45 turns of No. 22 wire. Space this coil $\frac{1}{4}$ inch from the antenna coil.

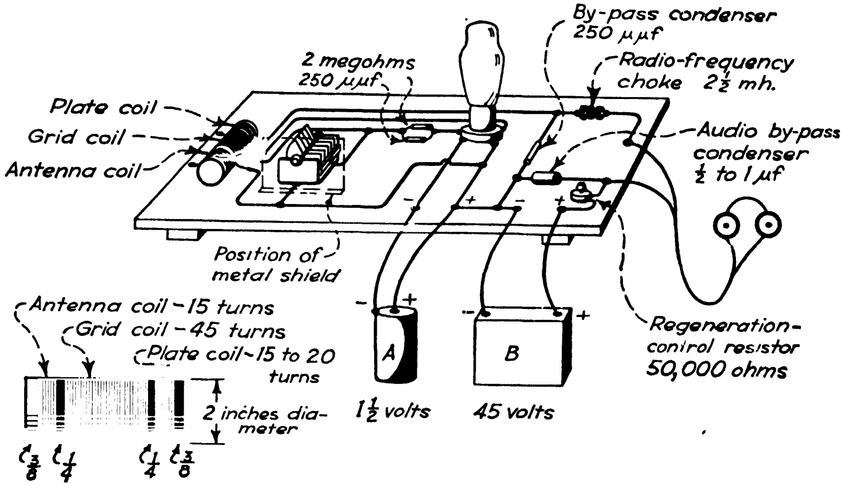


FIG. 195. Here is the layout of the new parts in the regenerative circuit.

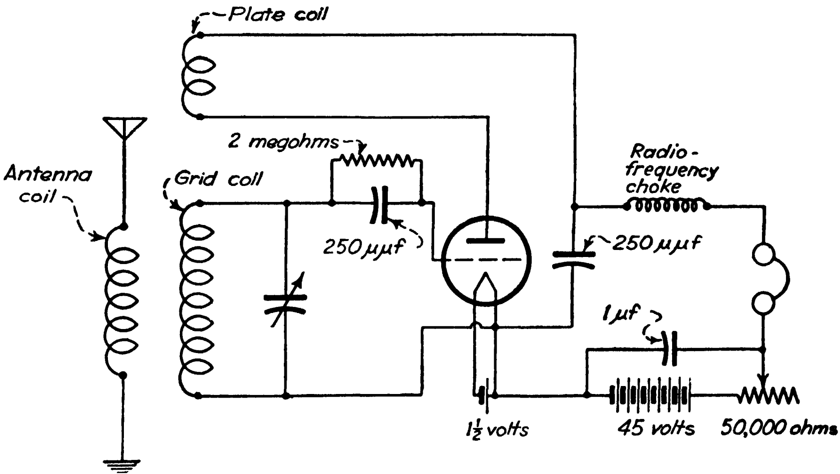


FIG. 196. This is the schematic wiring diagram for the regenerative receiver.

The Plate Coil. Wind 22 turns of No. 22 wire at the end opposite the antenna coil. Start ¼ inch from the end of the grid coil. Since the correct number of turns in this coil must be found by trial, it will probably be necessary to remove some of them, as will be explained in "How to Operate the Set" below.

Winding Instructions. It is very important in this set that the electromagnetic field of all coils add together. If the field of the plate coil opposes the field of the grid coil, the set will not oscillate.

Therefore, start at one end of the form and wind all coils *in the same direction.*

Mount the regeneration-control resistor. Mount the volume-control resistor having a range of 0 to 50,000 ohms as shown in Figs. 195 and 196.

How to Wire the Set

The Antenna Circuit. This circuit is the same as that for the one-tube receiver (see Figs. 177 and 178).

The Grid Circuit. This circuit is also the same as the grid circuit of the one-tube receiver.

The Plate Circuit. Run a wire from pin 3 of the tube socket to the plate coil. From the other end of the plate coil, run a wire to the $2\frac{1}{2}$-millihenry radio-frequency choke and to one terminal of the 250-micromicrofarad by-pass condenser. From the other end of the choke, run a wire to one of the earphone binding posts. Connect a 1-microfarad audio by-pass condenser between one earphone terminal and the B-negative terminal.

The Regeneration-control Resistor. Cut the wire connecting the B-positive terminal and the earphone terminal on the old set board, and insert the volume-control resistor. Be sure that one connection goes to the central, or slider, connection on this control.

How to Operate the Set

Step 1. Connect the antenna and ground wires to the set.

Step 2. Put a 1LE3 tube in the socket. Connect the $1\frac{1}{2}$-volt A battery. Connect the leads to the set before connecting to the battery, in order to prevent a short.

Step 3. Connect the B battery and earphones as follows: Connect the B battery to the B-positive and B-negative posts on the set. Attach the earphone cord tips to the earphone posts on the set. There should be a noise in the earphones when the tips are connected if this circuit is correctly wired.

Step 4. Make the set oscillate as follows: Turn the regeneration-control resistor, starting from its minimum-resistance setting, until the set's oscillation is indicated by a rushing sound or a soft hiss heard in the earphones. Test for oscillation by touching the grid terminal of the tube or the stator of the tuning condenser with your finger. A pop or thud should be heard if the set is oscillating.

Step 5. Tune in a station by means of the tuning condenser. Turn the regeneration-control resistor back slowly until the set goes out of oscillation. Stations will be heard with most volume with the resistor set as near the oscillation point as is possible without having the set oscillate. The set is most sensitive at this point.

To tune in stations, you use a different process.

Step 1. Set the regeneration-control resistor so that the receiver is oscillating.

Step 2. Then swing the tuning condenser slowly across the dial until you hear a high-pitched whistle. This whistle is caused by the carrier wave of a broadcast or transmitting station mixing with a radio-frequency oscillation built up in your receiving set.

Step 3. Now tune slowly until the pitch of the carrier whistle drops gradually to a low-pitched tone and then stops. If the dial is turned still farther, the whistle will start again at a low pitch and rise in pitch until it can no longer be heard.

The station you wish to hear should be found with the tuning condenser set at *zero beat* just between the two whistles. The zero-beat method of locating a station is much more rapid and more sensitive than the method you used on the one-tube set. But music or voices are mushy and distorted in tone.

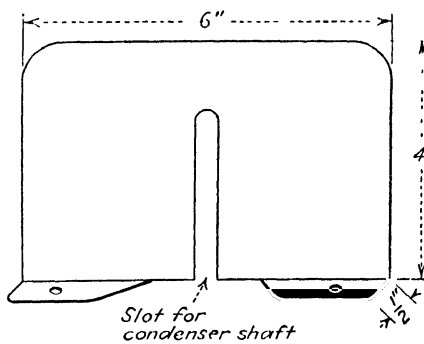


FIG. 197. How to make the condenser shield plate.

Step 4. Now turn back the regeneration-control resistor until the set just goes out of oscillation. Adjust it as closely as possible to the oscillation point. You will notice that the sensitivity of the set increases very rapidly as the oscillation point is approached, and that just below the point where the set goes into oscillation, the signals are strongest. After the set goes into oscillation, the signals are distorted and are not clear.

How can you eliminate the hand-capacity effect? If the set goes out of adjustment and starts to whistle, or squeal, when you remove your hand from the condenser knobs, the set is being affected by ***hand capacity.***

Make a tin or aluminum shield plate, and place it between the tuning-condenser dial and the condenser frame (see Fig. 197).

Fasten a wire from the shield plate to the ground or to the B-minus connection. This will stop the hand-capacity effect.

Some Troubles and Their Remedies

The set will not oscillate. *Cause.* The plate coil is wired backward; its field opposes that of the grid coil. *Remedy.* Reverse the connections at the plate coil.

Cause. Not enough turns on the plate coil. *Remedy.* Add 10 more turns. This may be too many, but you can cut down the number until the set operates correctly.

Cause. No radio-frequency choke or a shorted choke. *Remedy.* Hook a choke in the circuit, or put in a new choke.

Cause. Loose or broken wire joints. *Remedy.* Go over the joints of the set to see if one looks good but is not well soldered. This may be caused by dirty wires that have not been carefully scraped. Solder will not stick to a dirty wire. Flux will not clean wires. The wire must be scraped bright before putting on the flux. Another cause of poor joints is that the soldering iron or the joint is too cold. When the joint is hot enough, the solder runs into the joint quickly. Very little solder is needed to make a perfect joint.

Cause. Reversed A- or B-battery connections. *Remedy.* Check both A and B leads. The plate must be connected to the positive side of the B battery through the plate coil, the choke, and the phones. Trace this connection out carefully.

The set will not stop oscillating. The regeneration point occurs just before the set starts to oscillate. Here the set is more sensitive. If it will not stop oscillating, signals are not as loud as they might be.

Cause. Too much B voltage. *Remedy.* Reduce the B voltage.

Cause. Too many turns on the plate coil. *Remedy.* The number of turns on the plate coil should be such that the set will go into oscillation with the regeneration-control resistor half in. Set the regeneration control half in, put 45 volts on the plate, and take off turns on the plate coil, a turn at a time, until the set oscillates smoothly. Test the set after each turn has been removed.

The set oscillates too strongly. The set goes into oscillation with a heavy thud.

Cause. Too much B-battery voltage. *Remedy.* Reduce the B voltage to 45 volts.

Cause. Grid leak too large. *Remedy.* Try a grid leak with less resistance.

Cause. Too many turns on the plate coil. *Remedy.* Remove turns, one at a time.

The set screeches and howls.

Cause. B voltage too high. *Remedy.* Reduce the B voltage.

Cause. Too many turns on the plate coil. *Remedy.* Take off turns, a turn at a time.

The set is noisy or scratchy in operation. *Cause.* Tubes defective or old. *Remedy.* Try another tube.

Cause. Loose connections in the set wiring. This is noticed as a pop or as scratching when the set is jarred. Poorly soldered joints may be the cause. *Remedy.* Tighten all connections at the binding posts. Move the soldered joints with the fingers while the set is operating, to see if the joint is broken. A wire may be broken, so that the ends touch each other intermittently. Scrape and resolder the joint.

Cause. The regeneration-control resistor may be defective. The noise then is caused by the small changes in resistance, which produces erratic voltage changes in the plate circuit. *Remedy.* Tighten the screw holding the resistor parts together. Try a new resistor. If the new resistor tried in the circuit stops the noise, continue to use it.

Questions

1. About how many stages of radio-frequency amplification would you have to add in order to make a set as strong as a one-tube regenerative receiver?
2. Are your signals clearer before or after the set goes into oscillation?
3. What is meant by hand capacity?
4. Give a list of reasons why a set will not operate.
5. Make a list of reasons why a set will not stop oscillating.
6. Give reasons why sets may oscillate too strongly.
7. Give a list of reasons why a set screeches and howls or is too noisy in operation.

Trace the electron flow through the new plate coil. Trace the path of the electron flow of the plate current through the plate

circuit in Fig. 198. The electron arrows show that this current travels from the plate to the plate coil, which is wound near the grid coil. From the plate coil it goes through the radio-frequency choke, through the earphones, through the B battery, and back to the tube to complete the circuit.

What is feedback? The current that flows through the tube also flows through the plate coil. This current sets up a magnetic field around the plate coil, which links with the grid coil and induces a voltage in it. This process is called *feedback* because each radio-frequency surge through the tube feeds back a tiny bit of energy to the grid tuning circuit.

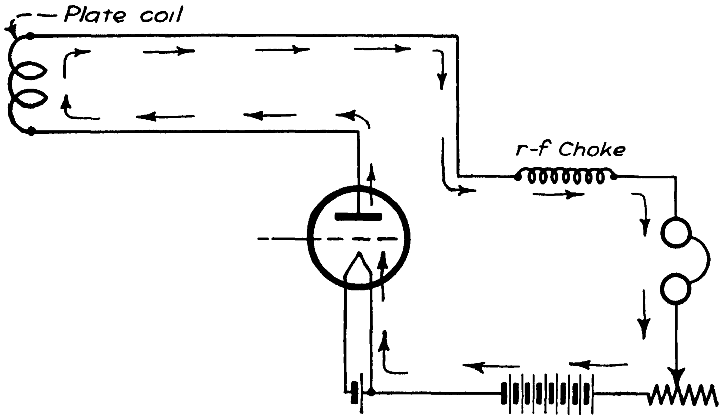


FIG. 198. The current that flows through the tube also flows through the *plate* coil on its way back to the B battery. It induces or *feeds back* a helping voltage in the grid coil.

The plate coil must be connected correctly. When the plate coil is wound in the same direction as the grid coil and the wires from the tube plate are connected correctly, the plate coil induces a helping voltage in the grid coil which makes the grid-circuit surges stronger. You can tell when the plate coil is correctly connected, because the set can be made to oscillate and faint signals will be louder.

When wired backwards, the helping effect of the plate coil is lost. Try changing these connections, and note the difference it makes in the strength of the signals. Connections are wired on the set board for this purpose, as shown in Fig. 199.

How does feedback make stronger signals? You found in the grid-condenser-grid-leak circuit that you could make the sounds in

the earphones louder only when the signal voltage on the grid was stronger. The grid condenser and leak made the voltage on the grid stronger in this circuit.

In the regenerative circuit, feedback from the plate coil makes stronger the surges in the grid tuning circuit. This, in turn, makes stronger the voltage which is forcing electrons on and off the grid. The higher voltage then makes greater changes in plate current, and sound is louder in the earphones.

But how far does regeneration go? You see, the feedback process continues, one effect building up the other to the limits of the tube, until the set is said to "go into oscillation."

What is oscillation? You know when the set is in oscillation, because you hear a hiss in the earphones. The set goes into oscil-

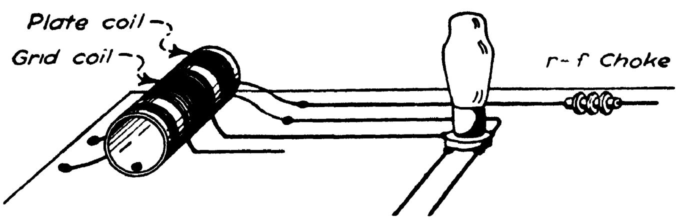


FIG. 199. Arrange flexible wires and two connectors so you can reverse the connections to the plate coil.

lation with a soft thud or with a shriek, depending on the plate voltage and other factors. When the set is oscillating, speech and music are distorted and unpleasant. You hear whistles and squeals as you tune your set.

Oscillation occurs in a circuit when enough power is fed back from the plate circuit to more than equal the power lost in the grid circuit. The voltage induced in your receiver by radio waves rapidly dies out because of the resistance of the wires and the wire joints in the antenna and tuning circuits. We try to keep the resistance low so that the strength of the voltage surges will be cut down as little as possible. These losses cut down the strength of the voltage on the grid, and the sound is weaker.

But in the regenerative circuit these losses are largely offset by the voltage that is induced, or fed back, into the grid circuit from the plate circuit. Power supplied from the B battery makes up the tuning-circuit losses.

What circuit losses do we find at resonance? If there were no resistance in the tuning circuit, the current flow at resonance would be large. The voltage on the grid would be strong, and the signals loud. At resonance, the back voltages of the condenser and of the coil cancel each other, because they are equal and opposed. So the only circuit loss is from the resistance of the wires and joints. But when you feed back just enough energy from the plate circuit to the grid circuit to equal the loss caused by resistance, the effect is the same as if there were no resistance in the circuit. When the amount of energy fed back just equals the losses, the circuit oscillates.

What occurs in the circuit during oscillation? With no resistance left in the circuit, the current surges in the grid circuit reach their maximum possible strength. Now, if you feed back even a trifle more current, you get the steady, continuous surging in the grid circuit that is called *oscillation*. Your set then oscillates steadily at the frequency to which it is tuned.

How is feedback, or regeneration, controlled? If the tube used in this set is a good amplifier and detector, enough energy can be fed back to make the set oscillate too strongly and produce screeches and howls, and while the program will be loud, it will be badly distorted and unpleasant to hear.

You can easily control regeneration by changing the strength of the plate current. This can be done by using a resistor to control the B-battery voltage (see the circuit in Fig. 200).

The 50,000-ohm volume control used to control regeneration is simply a resistance element mounted in a small circular case, arranged with a sliding contact so that you can change the resistance to suit your needs. The resistance element may be carbon, or it may be fine resistance wire wound on an insulating strip.

When the slider is moved to decrease the resistance, the voltage on the plate is increased, and more current flows through the tube and through the plate coil.

This makes the magnetic field of the coil stronger, and a helping voltage is induced in the grid coil. In this way the resistor controls regeneration.

How do the radio-frequency choke coil and the by-pass condenser filter out the radio-frequency surges? The other new parts in this circuit, the radio-frequency choke coil (r-f choke)

and the 0.00025-microfarad (250-micromicrofarad) by-pass condenser, need explanation (see Fig. 201). The coil and condenser form a filter circuit, which separates, or filters, the radio-frequency

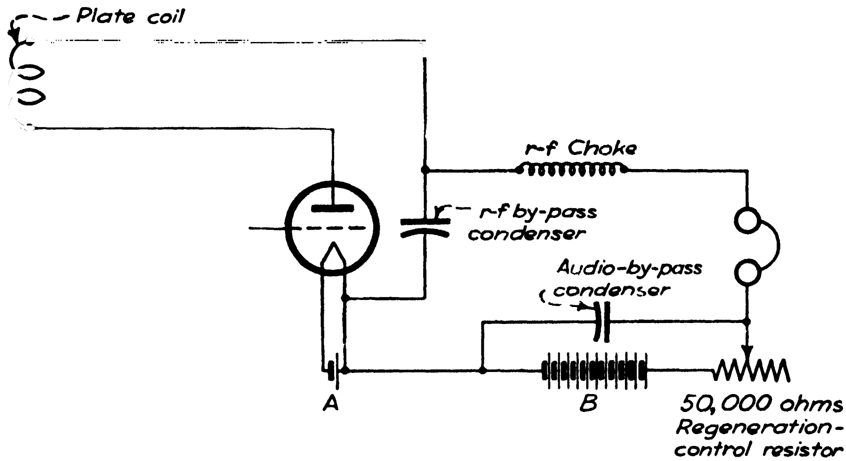


FIG. 200. This schematic diagram shows the way to connect the regeneration control resistor in the plate circuit. As you turn the control you change the plate voltage and so the plate current.

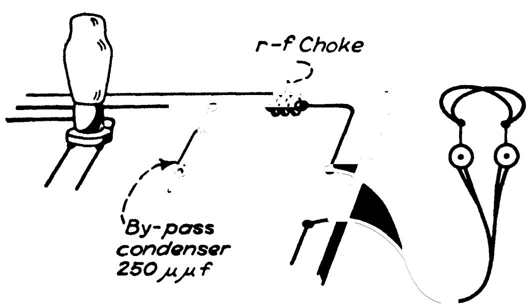


FIG. 201. More new parts. The radio-frequency choke coil and the by-pass condenser stop the radio-frequency surges in the plate circuit and blend them into slower surges at audio frequency which will operate the earphones.

surges of plate current that get through the tube from the low-frequency audio surges.

You found in the crystal-detector set and in the one-tube detector set that the radio-frequency surges of the carrier wave changed direction too fast to operate the earphones (see Fig. 202). But groups of surges were slow enough to operate the earphones. A

radioman would say that the radio-frequency choke stopped the radio-frequency surges, or radio-frequency component, but allowed the audio component, or surges, to pass through to the earphones.

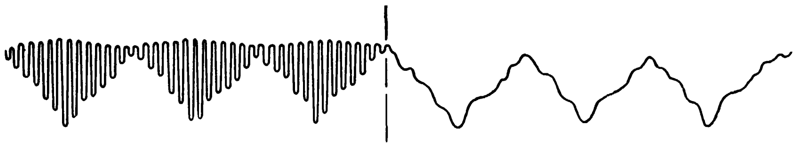


FIG. 202. The wave picture of the action of the radio-frequency choke and the by-pass condenser.

How does the filter work? The radio-frequency choke is designed and wound so that it will stop radio-frequency surges. Read again in Chapter 10 how the reactance of a choke coil increases as frequency rises ($X_L = 2\pi fL$). When the current

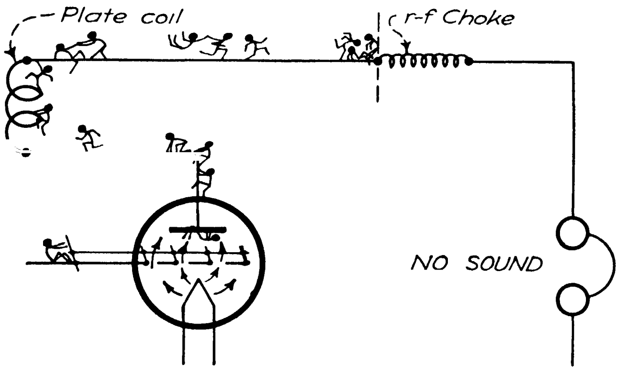


FIG. 203. The single radio-frequency surges come so fast that the back voltage which they set up in the radio-frequency choke coil stops them. No sound is heard in the earphones.

surges are changing very rapidly (at radio frequency) they set up much more back voltage than do slower audio-frequency surges.

Therefore, most of the electrons in the radio-frequency surges are stopped when they reach the radio-frequency choke coil (see Figs. 203 and 204). You hear no sound in the earphones, because

no current then reaches them. You can note this effect by temporarily removing the by-pass condenser.

But how can the energy in the radio-frequency surges get to the earphones? The by-pass condenser is the answer.

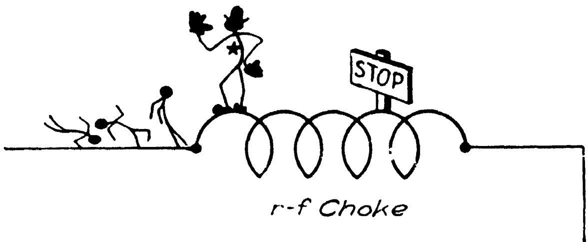


FIG. 204. The radio-frequency choke has much back voltage when the current surges occur very rapidly, at radio frequency. It has little back voltage when slow surges occur.

What does the by-pass condenser do? Because the by-pass condenser can store the energy between the radio-frequency surges, you hear sound. When the electrons in the radio-frequency surges

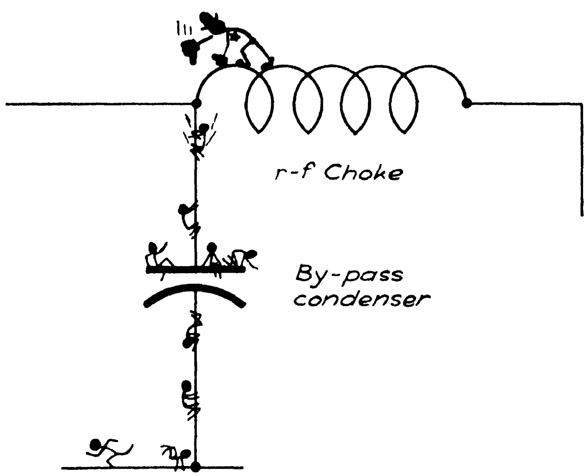


FIG. 205. The by-pass condenser offers the electrons a place to go instead of piling up at the radio-frequency choke. The pressure they build up at the choke forces them onto the condenser.

pile up at the radio-frequency choke, the back voltage forces them into the condenser (see Figs. 204 and 205). The by-pass condenser is small (250 micromicrofarads capacity) because it handles radio-frequency surges.

When the first radio-frequency surge dies down, the reverse back voltage of the choke pulls. The only electrons it now can get are those in the condenser, because at this instant no surges are coming through the plate coil from the tube. At the same instant, the back voltage of the loaded condenser pushes the electrons back to the choke and through it to the earphones (see Fig. 206).

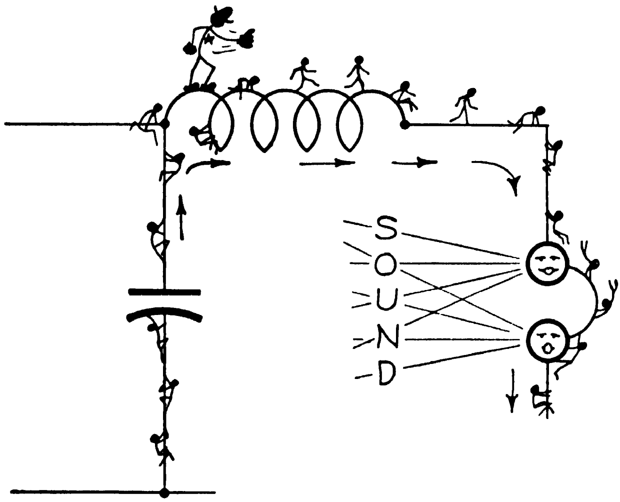


FIG. 206. When the surge through the tube ends, the collapsing field around the choke pulls. At the same instant the pressure of the electrons on the condenser drives these electrons out and through the choke and through the earphones.

The coil-condenser filter smooths the flow. The effect of the filter action is to cut down the peaks of current and fill in the valleys so that a slowly surging current results. Now a thousand or so radio-frequency surges blend into one surge (see Fig. 202).

The new surges are then slow enough so that they can get through the choke coil. They are at audio frequency. The choke has too few turns to build up sufficient back voltage to stop the slow audio surges. At this slow surge rate (frequency), it has practically no back voltage. These surges easily pass into the earphone coils, and you hear sound.

What is the purpose of the condenser across the B battery? The large capacity condenser connected across the B battery (see Figs. 207 and 208) allows the surges to by-pass around the B battery. The battery is a poor path for these surges, as you can

tell by disconnecting one side of the condenser. The sound is better with it connected. This condenser must be large, because the surges are slow at audio frequency. A large condenser takes longer to fill than a small condenser at the same voltage.

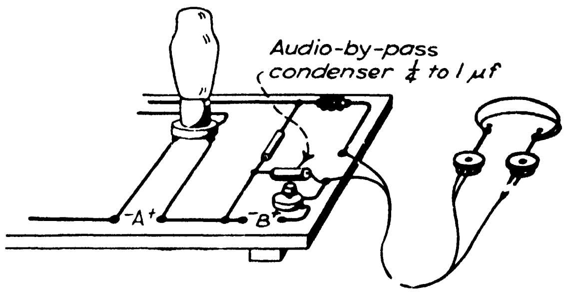


FIG. 207. Another new part in this circuit is the audio by-pass condenser across the B battery and the variable resistor.

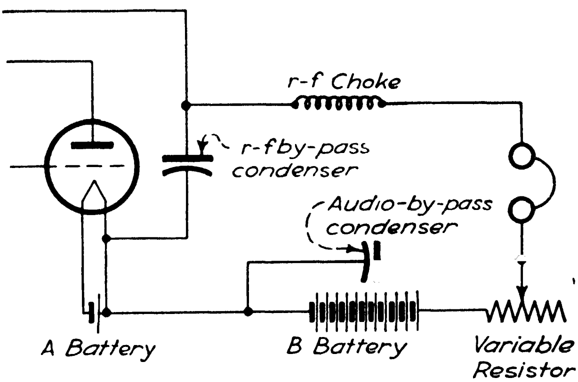


FIG. 208. Schematic diagram of the by-pass condenser across the B battery and the variable resistor.

Now, after you have studied the different parts of the regenerative circuit and have learned about the operation of each part, it may be well to collect these ideas into a summary.

Summary of Regeneration

A weak current in the antenna circuit (Fig. 209)
induces a weak voltage in the tuning circuit (Fig. 210).
This voltage in the tuning circuit drives electrons on or pulls them off the grid of the tube (Fig. 211)
and makes the grid more and less negative (Fig. 212).

Therefore, the plate current changes in strength—first strong, then weak, but (Fig. 213)

to make loud sounds in the earphones, there must be a considerable change in the plate current.

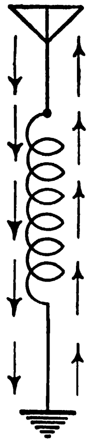


FIG. 209. A weak current in the antenna circuit.

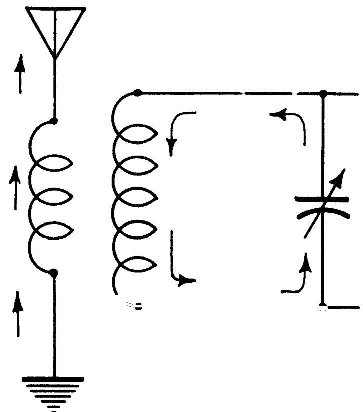


FIG. 210. A weak current in the antenna circuit induces a weak voltage in the tuning circuit.

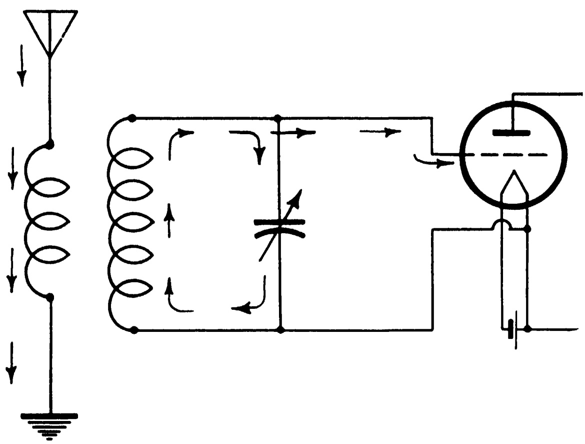


FIG. 211. The current surges in the tuning circuit drive electrons on and pull them off the grid of the tube.

And so, by using some of the strong plate current to help the weak grid voltage, we can get louder sound (Fig. 214).

We can do this by passing the plate current through the coil. This induces a helping current into the grid coil (Fig. 215).

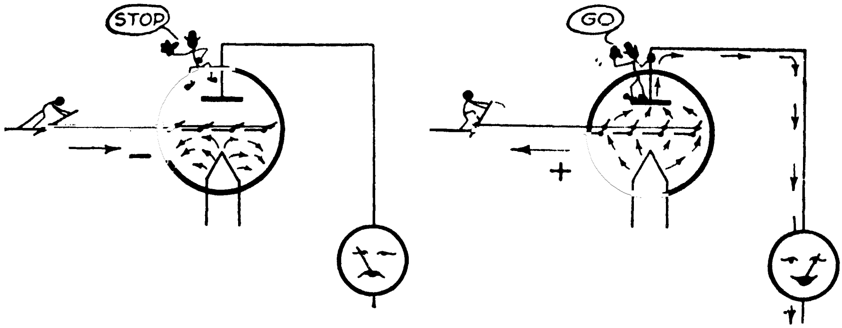


FIG. 212. As the grid becomes positive or negative it controls the flow of the plate current.

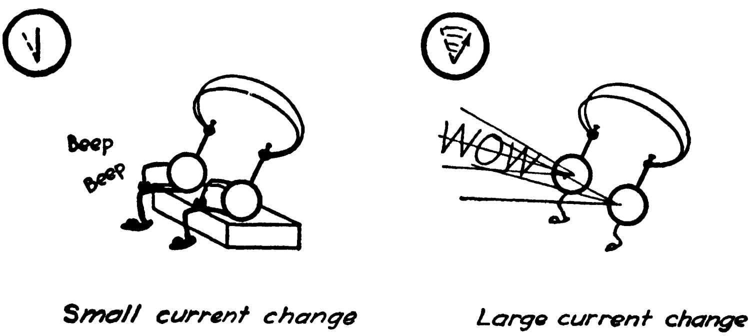
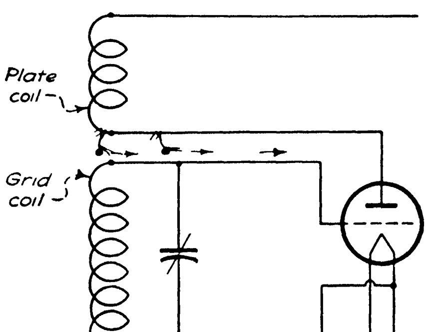


FIG. 213. Small current changes make weak sounds, large current changes make strong sounds.



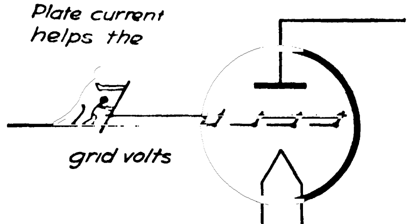


FIG. 214. By causing the plate current to flow through the new *plate coil*, a helping voltage is induced in the grid coil.

FIG. 215. Now more electrons are forced on and off the grid by the stronger voltage in the tuning circuit.

Now, because more electrons are forced on and off the grid by the stronger current in the tuning circuit (Fig. 216),

the changes in plate current are much stronger and the music is louder.

The setting of the regeneration-control resistor controls the amount of feedback current and the regeneration (Fig. 217),

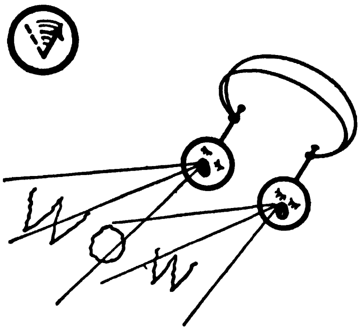


FIG. 216. The changes in plate current are larger and the music becomes louder.

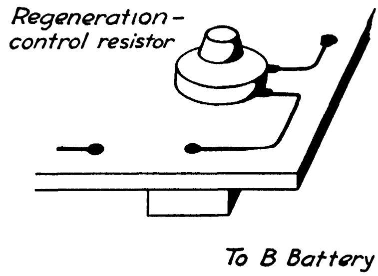


FIG. 217. The setting of this condenser controls the amount of plate current that flows, which in turn controls the feedback to the grid coil and the amount of regeneration.

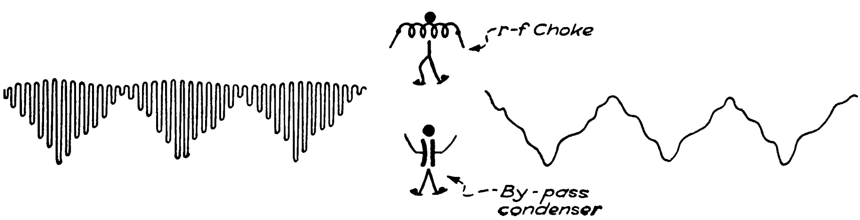


FIG. 218. The radio-frequency choke and the by-pass condenser help by separating, or regrouping, the radio-frequency surges into groups. We now have a fine set.

and so the set will play loudly but will not howl.

The radio-frequency choke and the by-pass condenser help by separating, or regrouping, the radio-frequency surges into bunches (Fig. 218) which operate the earphones easily. And we now have a fine, sensitive set for long-distance reception.

Questions

1. What is meant by *feedback?*
2. What is the effect of winding the plate coil in the opposite direction from that of the grid coil?

3. When does oscillation occur in a set?
4. What would you add to your set to control regeneration?
5. What is the purpose of the radio-frequency choke coil?
6. What is the purpose of the by-pass condenser?

PART 4: KINDS OF AUDIO-FREQUENCY AMPLIFYING CIRCUITS

When De Forest added the grid to the vacuum tube, he made possible electrical leverage, or amplification. He made a then comparatively useless vacuum tube into a valuable commercial device whose possibilities are now being rapidly developed by science and engineering. You have seen in your study of the operation of the detector, as well as of regeneration, how a few electrons on the grid control a strong flow of electrons through the tube. The strong plate current follows every variation of the weak grid voltage. This illustrates the electrical leverage, or amplifying action, of the tube.

A new line of development became possible. Now the weak electron flow from an antenna, which is measured in millionths of a volt (microvolts), when connected to the grid of the tube, controlled the strength of the current from the B battery through the tube, which was thousands of times stronger than the electron flow in the antenna.

In the grid-condenser grid-leak detector, you learned how to use this antenna voltage more efficiently. You learned to amplify, or strengthen, its effect, so that the sound was stronger than that delivered by the simple detector set. Regeneration was another way to do more of the same thing.

However, both the grid-condenser grid-leak detector and the regenerative circuit have limitations. Although the grid-leak detector added a relatively small increase to the signal strength and proved to be an excellent circuit for weak, distant signals, it could not handle strong signals well. The regenerative receiver you found to be very sensitive, but critical in its adjustment. When you study the audio-amplifier circuits, you will find that they are easy to build and easy to use and that they need but little added equipment. These circuits need no adjustments and are stable in operation. They can increase the volume of sound from your set until it is unbearable.

You can build and wire two amplifier units, hook them to your

Bell Laboratories Record

PRINTED-WIRE CIRCUITS PROVIDE A NEW WIRING TECHNIQUE

The printed-wire circuit board permits the use of automatic machines to assemble the components of the circuit and to solder automatically all connections at one time This woman is making the master layout for a printed wire circuit

detector, and get your favorite program loud enough from a speaker so that your friends can enjoy the set with you.

You will have to learn how to connect these different circuits together so that they will operate efficiently. As you remember, the method of joining one circuit to another is called *coupling* You will learn how to couple the detector to the audio-amplifier circuit, as well as learn ways to couple the amplifier units together.

Here are some new things to learn about:

1. The circuit of the transformer-coupled amplifier
2. The circuit of the resistance-coupled amplifier
3. The power audio amplifier
4. The use of the C, or bias, battery

Why is coupling important? The kind of coupling circuit you use is important, because you must carry the signal from one circuit to the other efficiently; you can lose much of the amplified signal if the circuits are improperly coupled. The first set you studied, the crystal detector, was directly coupled to the antenna. Part of the voltage induced in the antenna by the radio waves forced electrons to flow through the earphones and to produce sound.

In the next set, the one-tube circuit, you also used direct coupling. Neither set was efficient. But both brought in programs and helped you learn a bit more about radio.

What is inductive coupling? When you studied tuning, you used a different kind of coupling. You then wound a primary coil and a secondary coil to form a transformer. When you connected the antenna to one coil and the condenser to the other, you had inductive coupling between the two circuits. The voltage and current in the secondary were set up by induction.

When inductive coupling is used, the antenna current can surge freely in its own circuit without having to operate a tube or a crystal. Only a part of its energy is used to drive the tuning circuit.

The tuning circuit can also operate freely. If the tuning circuit were coupled directly to the antenna, it would send more interfering current back into the antenna circuit than if it were loosely coupled. As you learned in Chapter 11, "Resonance and Tuning," the two circuits must be separated, or loosely coupled, to keep interference between them down to a minimum.

What is capacitive coupling? You can also connect your antenna to the tuning coil through a small fixed condenser, as shown in Fig. 219. This method can be used either for the crystal or the one-tube detector. It is called *capacitive coupling.*

While capacitive coupling is simple and uses few parts, it will cause more interfering voltage to be sent back from the tuning circuit to the antenna than will a well-designed inductive-coupling arrangement.

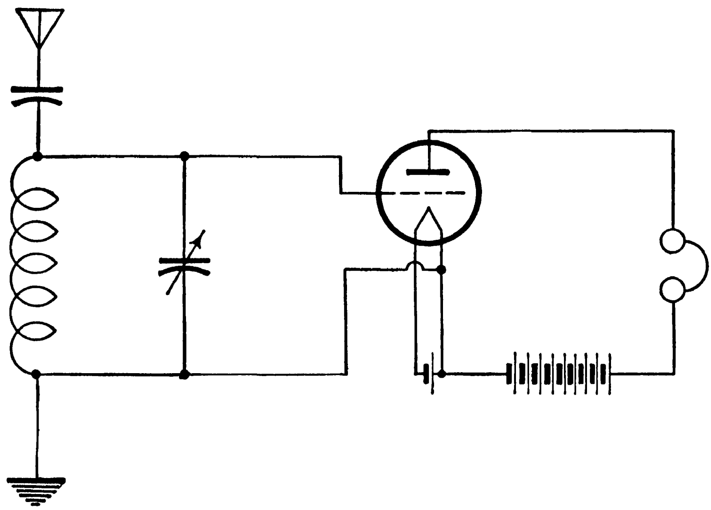


FIG. 219. Capacitive coupling is a simple and inexpensive method of coupling two circuits together. Here the antenna circuit is coupled to the tuning circuit through a fixed coupling condenser.

You will find, however, as you study amplifier circuits, that capacitive, or condenser, coupling is very effective. You will find it used in transmitter circuits, between transmitter and antenna, and in many other circuits.

But, first, study the audio-amplifier circuit.

PART 5: HOW TO BUILD A TRANSFORMER-COUPLED AUDIO-FREQUENCY AMPLIFIER

Why is coupling needed? You could run a direct wire from the plate of the detector tube to the grid of the amplifier, but the set would not play. This connection would force few, if any, electrons to the amplifier tube. The detector B battery would make the amplifier-tube grid highly positive; much plate current would

flow and the tube would get hot, but you would hear little or no sound. However, by separating the detector plate circuit from the amplifier grid circuit, you can make the amplifier operate nicely.

Is there more than one kind of coupling? You will study here two ways of coupling these two circuits: (1) by means of a transformer and (2) by means of a condenser and resistor.

The transformer-coupled amplifier has certain advantages. The transformer is small and is easily wired into the circuit. It uses lower B-battery voltages than the resistance-capacity-coupled circuits you will study later. One disadvantage is the higher cost of the transformer.

Questions

1. Compare the advantages of the transformer-coupled amplifier with those of the resistance-coupled type.
2. Why is coupling so important?
3. What is meant by inductive coupling?
4. Compare the advantages of inductive coupling with those of capacity coupling.

How to Build and Wire the Set

Use a small set board. Use an audio-frequency transformer with a 2:1 or 3:1 turns ratio. You will also need a wafer-type

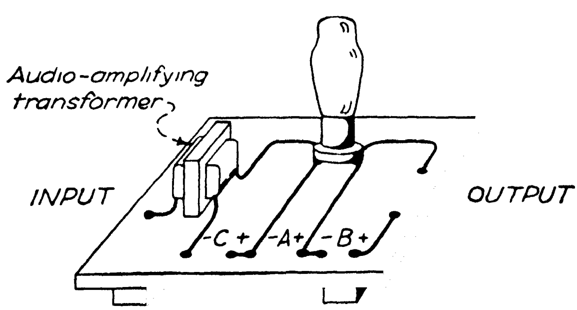


FIG. 220. Layout and wire the audio-amplifier board as shown here.

octal-tube socket. Mount the parts as shown in Fig. 220. Wire as shown in Fig. 221.

The Filament Circuit. Run wires from the filament pins 1 and 8 on the wafer socket to the A-plus and A-minus posts.

The Input Circuit. Run wires from the input posts to the P and B-plus connection on the primary of the audio transformer.

The Grid Circuit. Run one wire from the G terminal of the audio-transformer secondary to the grid connection (pin 6) on the wafer socket.

Run a wire from the F terminal of the audio-transformer to the C-minus terminal. The C-plus terminal connects to the A-minus post.

The Output Circuit. Run a wire from the P post on the tube socket (pin 2) to one output post. The wire from the other out-

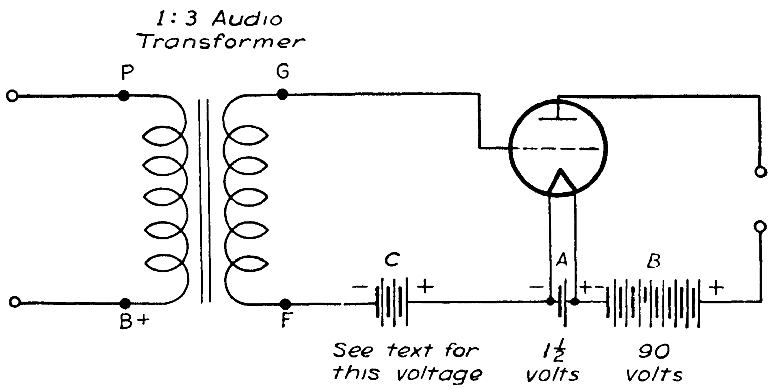


FIG. 221. Schematic circuit for the transformer-coupled audio amplifier.

put post attaches to the B-plus post. Finally, the B-minus post connects to the A-plus post.

How to Hook Up the Amplifier

Hook up the one-stage amplifier to a grid-condenser grid-leak detector. (The word *stage* means a single amplifier tube and circuit.)

Step 1. Attach wires between the output, or earphone, posts on the detector set board to the input posts on the amplifier board (see Fig. 222).

Step 2. Connect a $1\frac{1}{2}$-volt A battery to the detector and another $1\frac{1}{2}$-volt A battery to the amplifier, as shown in Fig. 223. You will learn later how to use only one A battery for the entire set.

Step 3. Connect a wire between the two C terminals on the amplifier board (see Fig. 224). Connect earphones to the amplifier-output terminals.

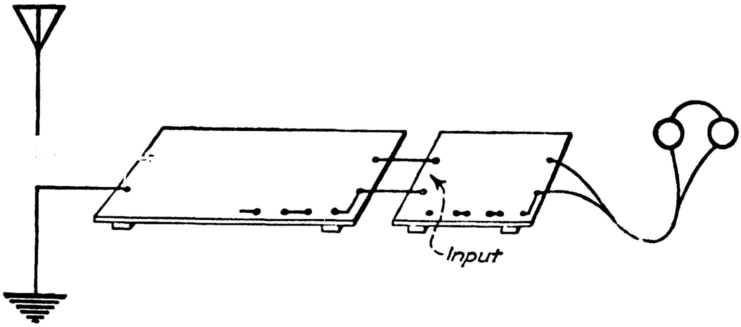


FIG. 222. *Step 1*, connect the wires between the detector output and the amplifier input posts.

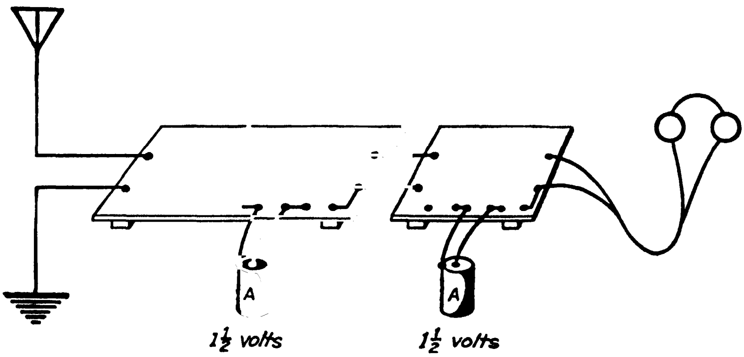


FIG. 223. *Step 2*, connect an A battery to the detector and to the amplifier board.

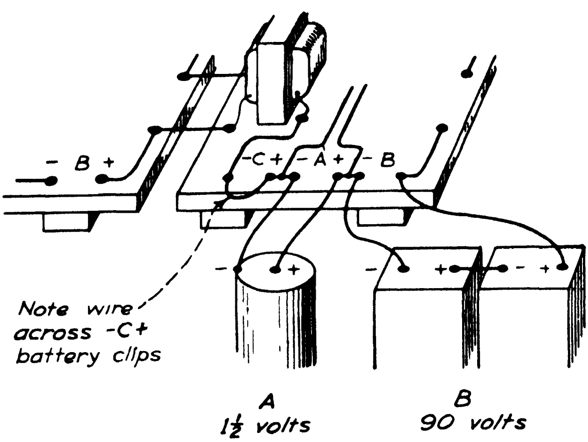


FIG. 224. *Step 3*, connect a wire across the C-plus and the C-minus connections on the amplifier board.

Step 4. Connect the B battery to the amplifier (see Fig. 225). First, try 45 volts on the B battery, then add B batteries until you find a voltage that gives the best results. Listen for the loudest music that is still clear.

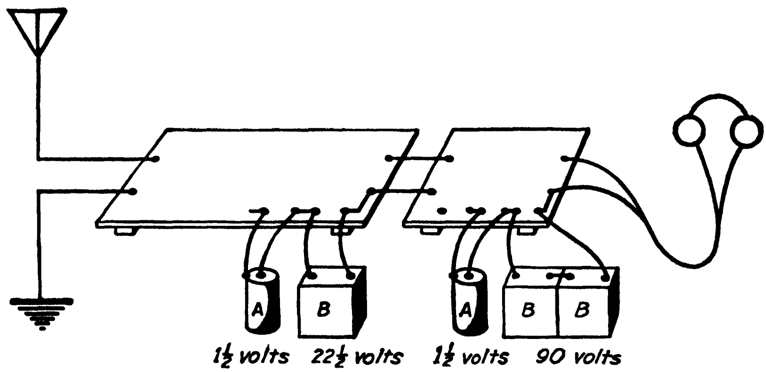


FIG. 225. *Step 4*, connect the B batteries to the two boards. Note that separate B batteries are used in this hookup.

What B-battery Voltages Should Be Used

The voltage you use on the tube filament and on the plate is quite important. Some tubes operate well as detectors with low B voltage, such as 22½ volts. But raise this to 90 volts or more and they detect poorly. Instead, they become excellent amplifiers.

Each tube is designed for definite A and B voltages which must be used if the tube is to operate efficiently as a detector or as an amplifier. You will find most of these voltages in the Radio-tube Characteristics Charts, pages 668–693, or in manufacturers' tube manuals.

When the correct B voltage is used on the amplifier, the music will be heard as loud as it can be brought in. Using too low or too high voltages seldom results in clear music and speech.

The manufacturer recommends in his tube manual the proper B voltage to use. He has made extensive and accurate tests to find the best operating point for the tube. Follow his recommendations closely to get the most out of the tube and circuit.

Try first B battery voltages for the audio amplifier between 45 and 90 volts. Test the plate voltage at the B-plus and B-minus

terminals of the detector and the amplifier, not at the battery. Then try the B voltage recommended by the manufacturer in the tube chart.

How to Operate the Set

Turn on the A battery. Put on the earphones. Tune the detector to your favorite broadcasting station. You should hear it with good volume. Nearby stations may be loud enough to hear with the receivers lying on the table.

Why It Works

As you learned in studying the one-tube detector circuit, the electron flow in the antenna sets up a weak voltage on the grid. As the grid voltage changes, the plate current changes, becoming alternately stronger and weaker to reproduce the sounds entering the microphone at the broadcasting transmitter.

In the detector these changes in strength of the plate current move the earphone diaphragms to make sound. But when you attach an amplifier to the detector, the plate current is passed through the primary of the audio transformer.

When the current flowing through the primary becomes stronger, the field around the primary spreads out and becomes stronger. As it expands, the field induces a voltage in the secondary. Then, when the current in the primary weakens, the collapsing field around the primary moves inward across the secondary turns and induces a secondary voltage in the opposite direction.

Rule. An alternating voltage is induced in the secondary when a pulsating direct current flows in the primary.

This audio transformer has three times as many turns on the secondary as on the primary and, therefore, is called a *step-up transformer.* As the field from the primary cuts across the many turns in the secondary, it sets up a higher voltage across the secondary. This higher secondary voltage forces more electrons on the amplifier grid than the weak antenna current could force on the detector grid.

Voltage Changes on the Amplifier Grid

Since the audio transformer has a turns ratio of about 1:3, you should find about 3 volts across the secondary for every volt across the primary.

The higher voltage of the amplifier B battery causes more plate current to flow through the amplifier tube than flows through the detector tube. The amplifier plate current is about 3 milliamperes as compared to $1\frac{1}{2}$ milliamperes for the detector. Now that you have more voltage on the grid of the amplifier tube, you can get much larger changes in the strength of the amplifier plate current. The plate current is now strong enough to operate a speaker when a strong nearby station is being received. For most signals, earphones will still have to be used.

PART 6: HOW TO BUILD A RESISTANCE-COUPLED AUDIO AMPLIFIER

How to Build and Wire the Set

Mount the parts on a small baseboard, as shown in Fig. 226.

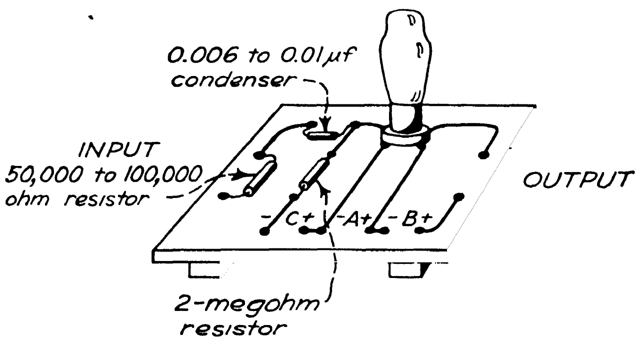


FIG. 226. The board layout for the resistance-coupled audio amplifier.

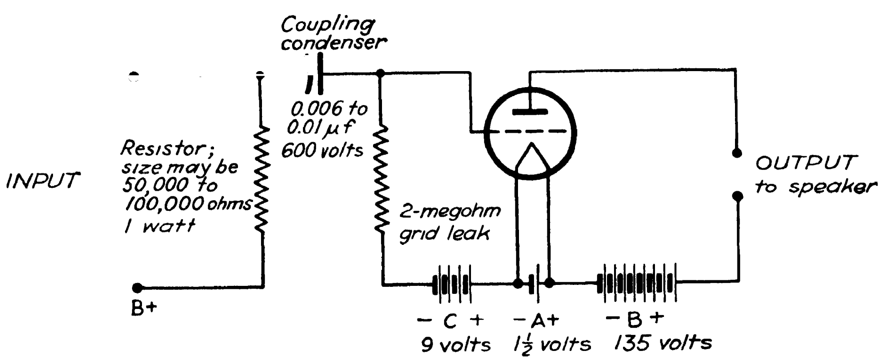


FIG. 227. Schematic circuit of the resistance-coupled audio amplifier.

The Input Circuit. No transformer is used in this circuit. In its place are two fixed resistors, one of 50,000 to 100,000 ohms and the other a 2-megohm grid leak (see Fig. 227). The fixed-

coupling condenser may have any capacity between 0.006 and 0.01 microfarad.

The Filament Circuit and the Plate Circuit. Wire the filament and plate circuits as shown in Figs. 226 and 227.

How to Operate the Set

This amplifier is in operation when the A battery and B batteries are connected. There are no adjustments to make on this set. Use a 1LE3 tube when earphones are connected to the amplifier. Use a 1LE3 for a speaker. You can also use other triodes by changing the wiring of the tube socket.

What Are the Advantages and Disadvantages of Resistance-coupled Amplifiers?

The high resistance used in the detector plate circuit of this amplifier makes it necessary to have a high B voltage. For a 1LE3 tube, you need 90 volts on the detector plate for resistance coupling, where $22\frac{1}{2}$ volts would do with transformer coupling.

Audio howls are less likely to occur in the resistance-coupled amplifier, because there is no transformer to cause feedback. The advantage of a well-designed amplifier of this type is that signals of a very good quality are obtained when it is used. There are no transformer losses in this circuit. However, the amplification is not high, whereas with the transformer coupling a higher amplification may be had.

Three resistance-coupled stages are needed to equal the output of two transformer-coupled stages (see Fig. 228 for this circuit and Fig. 229 for the way to connect the batteries).

Noninductive (non-inductive) resistors should be used in this amplifier. Carbon resistors are satisfactory. The coupling resistance should be twice the plate impedance of the tube. If the coupling condenser is too small, below 0.006 microfarad, the bass notes will be weakened or cut out. A larger size can be used if several stages of resistance coupling are to be used; the same size of condenser will do for each stage. This condenser must have good insulation, since leakage will destroy its efficiency. Current leaking through the condenser will affect the bias of the amplifier tube and will cause distortion.

"Motorboating" in a resistance-coupled amplifier may occur

when a power supply is used in place of B batteries. Motorboating is not noticeable with a one-stage amplifier but is bothersome when several stages are used. Motorboating is caused by feedback

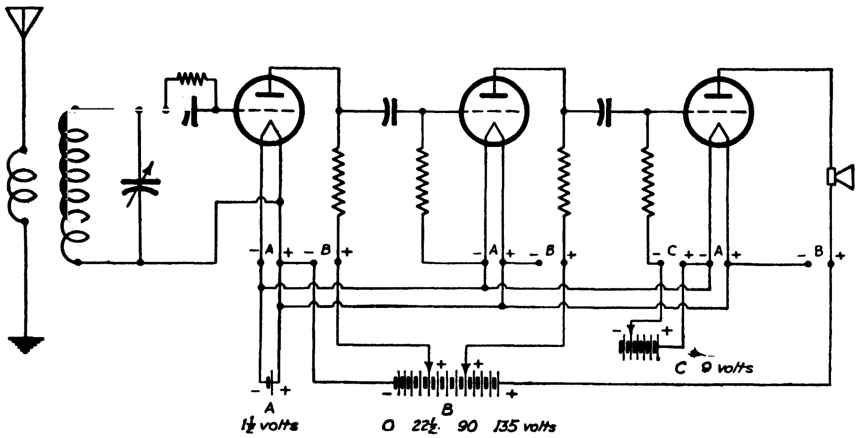


FIG. 228. This is the schematic circuit for a two-stage, resistance-coupled audio amplifier.

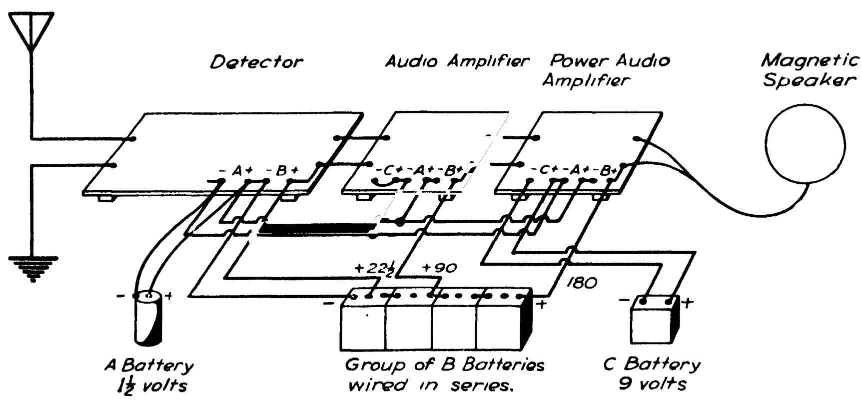


FIG. 229. This shows the connections of the batteries for a two-stage, resistance-coupled audio amplifier.

through common plate connections. One remedy is to attach a 20-mf filter condenser across the power supply.

Why It Works

Electrons on the way from the detector plate in Fig. 230 to the B battery are held back by the high resistance of the coupling

resistor. The resistance here is steady. Surges from the detector tube, which cannot rush easily through the resistor, drive electrons onto side *A* of the coupling condenser and, in turn, drive surges from side *B* to the amplifier-tube grid. The condenser capacity must be large enough to allow all audio frequencies to get to the amplifier-tube grid.

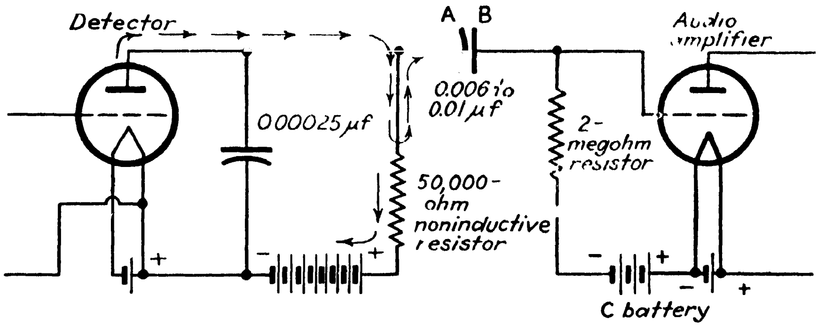


FIG. 230. Use this diagram to explain the operation of the resistance-coupled audio amplifier.

This type of coupling produces signals of good fidelity, since the voltage drop caused by the resistor does not change with frequency.

Questions

1. Why cannot the grid of the amplifier tube be connected directly in the plate circuit of the detector tube?
2. What determines the impedance of the primary of the audio transformer?
3. Compare the connections of a resistance-coupled set with those of a transformer-coupled set.
4. What is the purpose of the fixed condenser in the resistance coupling?

PART 7: HOW TO BUILD A POWER AUDIO AMPLIFIER

The power audio amplifier is simply a second amplifier stage added to the first. The output of the first amplifier stage is used to drive the grid of the second amplifier tube. Enough current flows in the plate of the second amplifier stage to operate a speaker. You get this added current by using both higher B-battery voltage and a power tube to control the increased plate current that flows. You can now hook up a detector and two stages of audio amplification.

Build and wire the set. The power amplifier board is the same as the one shown in Fig. 220.

Hook up the circuit. Connect two wires from the output posts of the first amplifier to the input posts of the second amplifier (see Fig. 231).

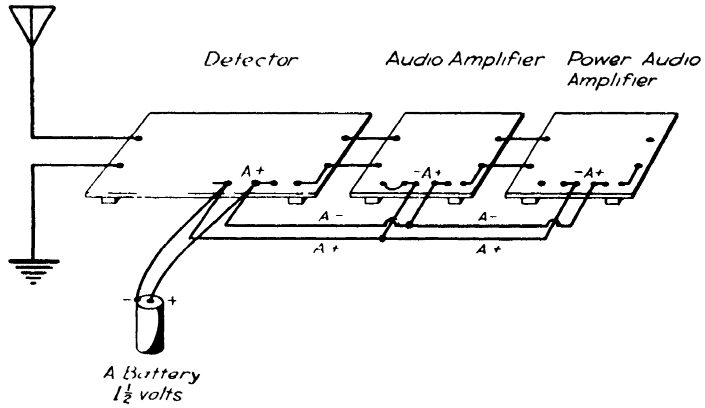


FIG. 231. One A battery will do for the detector and for both the amplifier boards when the boards are connected as shown here. The filaments are connected in parallel.

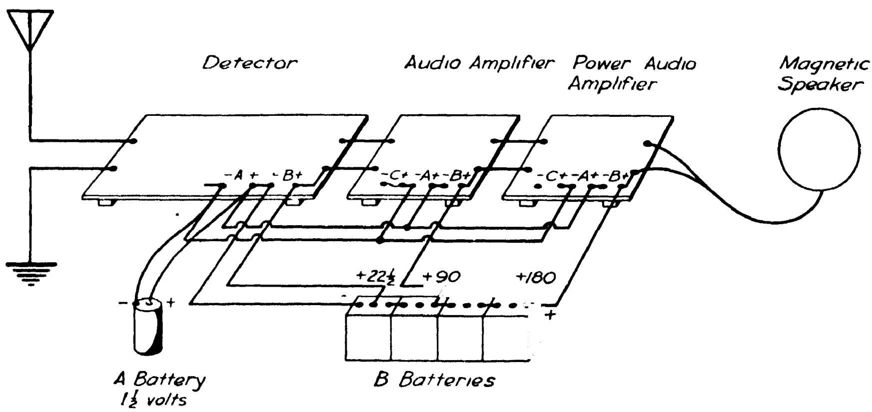


FIG. 232. By connecting all of the B batteries in series, four batteries are enough for the three tubes. Note that the B-minus connection from the first battery is also connected to the amplifiers through the A-plus wires.

Connect the A battery. One A battery can be used for all three circuits by connecting the A terminals on the boards in parallel. Do this by running wires from the first set board, as shown in Fig. 231.

Connect the B batteries. One group of B batteries may also be used for all three set boards. First, connect four B batteries

together in series to get 180 volts (see Fig. 232). Then connect the B-minus end of the first battery to the detector B-minus post. Connect a wire from the detector B-plus post to the first battery, so that the detector has 22½ volts on its plate.

Now run a wire from the detector B minus to each of the two amplifier stages, connecting the wire to their B-minus posts.

Connect a wire from the B-plus post of the first amplifier stage to the 90-volt tap on the second B battery. Connect the power-amplifier B plus to the 180-volt tap at the end of the fourth B battery.

Connect a wire across the two C-battery terminals on the power-amplifier board. Attach a magnetic speaker to the output terminals of the power-amplifier stage.

Caution. Use *no* earphones with this circuit because the power output is great enough to damage them.

For what is the power-amplifier tube used? First, use a 1LE3 tube for the amplifier. Although the music will be louder, it may have considerably more distortion than it should.

A power-amplifier tube is designed so that voltages on its grid cause large changes in the plate current. The grid wires are closer together than for a detector tube, and they may be closer to the filament. Such a grid has good control of the plate current. You can use a power tube for a detector or for a first amplifier, but the set plays better when the correct tubes are used. The detector and amplifier tubes are designed to give large voltage changes, whereas the power-amplifier tube is designed to produce large current changes. For this reason the detector and first amplifier tube are often called voltage amplifiers, and the power tube is called a current amplifier. You will learn more about power tubes when you study alternating-current tubes.

Now, when a speaker is connected across the output of the power stage, large changes in current produce enough motion of the paper cone to make the music much louder than with earphones.

How to operate it. Attach the A batteries to the filament circuit so that the tube filaments heat. Tune the detector circuit, and the set is in operation. Try different plate voltages on the power amplifier to see when the music is loudest. Also note at what voltage you get the least distortion of the music.

The C battery, made by wiring 15 flashlight cells in series and

mounting them in a small box, has the positive end connected as shown in the diagram, Fig. 233. Attach a test point or a clip to the C-minus connection on the amplifier board.

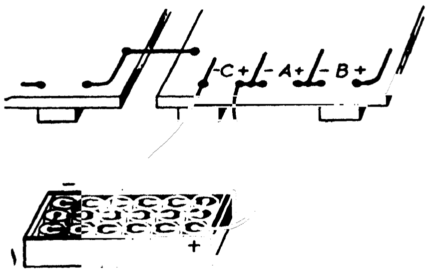


FIG. 233. Connect the C battery to the C posts on the *power* amplifier only. It is seldom needed on the preceding amplifier stage.

Now move the clip connection from cell to cell until you get both the loudest and the clearest music. Fasten the C-battery clip to this battery. (The C-battery clip must be moved when the B voltage is changed.)

Why it works. As the plate current of the first audio stage changes in strength, it induces an alternating voltage in the secondary of the coupling transformer. This induced voltage on the power-tube grid is higher than that on the grid of the first audio tube.

There is a small change in the detector plate current. It would be enough to operate earphones, but when the audio amplifier is connected, the change induces an alternating voltage in the secondary of the coupling transformer, which is connected to the grid of the second amplifier tube.

With 90 volts on the second tube, more plate current flows. The voltage on the grid of the second tube is higher than that on the grid of the detector tube, and so it causes larger changes in plate current.

The voltage on the grid of the power-amplifier tube is still higher, and the changes in the plate current of this tube are the largest in the set. They are large enough to operate a speaker. In a later chapter you will study power tubes that handle much more current and produce sound of greater volume.

What is the purpose of the C battery? The alternating voltage from the second amplifying transformer makes the grid of one power tube as much as 12 volts positive and 12 volts negative on strong signals. Find this in the Negative-grid-volts column of the Condensed Data Section, pages 670-693. The data in this tube chart show that the 1H4G type requires minus 13.5 volts for its operation when the plate voltage is 180. You will find that with 13.5 volts of C battery the music is loudest and clearest. A loud

signal will cause a 13.5-volt change on the grid; this must be offset by the C battery to prevent distortion in the music.

What causes distortion? The voltage changes on the grids of the amplifier stages and the plate-current changes in each stage must have the same wave shape as the current changes at the microphone in the broadcasting studio, if the music or sound you hear is to be true and undistorted. The height of each of the individual loops above and below the zero line of the wave must

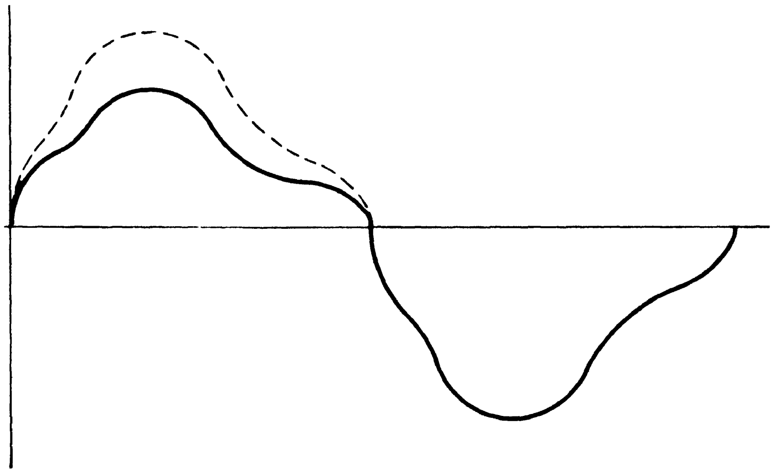


FIG. 234. When the grid becomes positive, it collects a few electrons from the space charge, and the wave is less positive than it should be. This produces distortion.

be proportional to the height of the corresponding loops at the microphone. Each amplifier stage simply increases the height, or amplitude, of each surge but keeps its height in exact proportion to the height of the original wave.

With no C battery, the positive loops are too low. You remember that when the grid became positive in the grid-leak grid-condenser circuit, the grid attracted electrons from the space charge.

When the amplifier grid becomes positive, it also collects electrons. On the positive loops, which should be, let us say, 13.5 volts positive, the grid may only become 6 or 8 volts less negative, because of the electrons the grid collects from the space charge. The wave shape shows that the loops are now out of proportion, and the music sounds are distorted (see Fig. 234).

What is the effect of C bias? You prevent distortion by using a 13.5-volt C bias. This makes the grid so negative that even with the strongest signal from the preceding amplifier the grid never becomes positive. This will cause no harm to the music, because the grid, instead of going positive and negative, starts at a point 13.5 volts negative and becomes more negative and less negative (see Fig. 235). An example makes this clear.

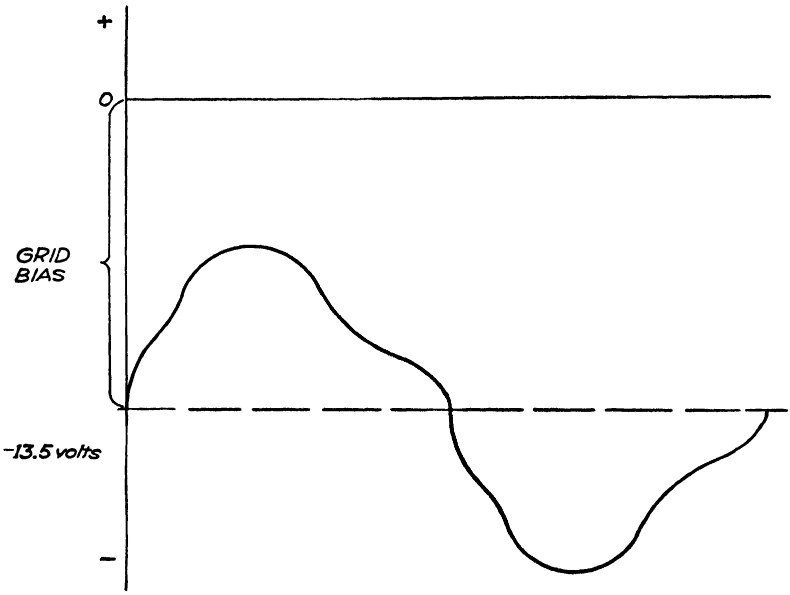


FIG. 235. With a negative grid bias, the grid is kept so negative that the signal cannot make it positive. It just becomes more and less negative. The music is now clear.

Suppose that a 10-volt signal is on the power-amplifier grid. Without a C battery, it would make the grid alternately 10 volts positive and 10 volts negative, and the music would be distorted. With the 13.5-volt negative bias, however, the grid becomes 3.5 volts negative (10-volt positive signal − 13.5-volt negative bias = 3.5 volts negative) and 23.5 volts negative (10-volt negative signal + 13.5-volt negative bias = 23.5 volts negative). This is the same as if the zero operating point for the grid had been dropped down to 13.5 volts negative and the grid operated above and below this point.

How does C bias affect plate current? Less plate current now flows, because the tube grid is more negative than before. However, the plate current becomes alternately stronger or weaker than

it did before. Its wave shape remains the same (has the same proportions) but, because the grid collects no electrons, the music is clear and has a minimum of distortion.

Questions

1. Should you use a speaker or earphones on a power audio amplifier? Explain
2. Why is C bias important in this set?
3. How can you prevent distortion?
4. Does C bias increase or decrease the plate current?

Technical Terms

amplification—The process of increasing the strength of signals.

antenna coil—The coil connected in the antenna-ground circuit.

cutoff point—The negative grid voltage, caused by electrons collected on the grid, at which the flow of plate current is completely stopped, or cut off.

detector—As used here, a vacuum-tube circuit used to convert radio-frequency pulsations into audio-frequency pulsations, which will produce sound in the earphones.

DX—An abbreviation used by radio amateurs meaning distance.

feedback—A voltage induced in the grid coil by the pulsating plate current flowing through the plate coil in a regenerative receiver.

grid bias—A steady pressure of electrons kept on the grid.

grid coil—The coil connected to the grid of the tube.

grid condenser—A 0.00025-microfarad fixed condenser connected in the grid wire.

grid leak—A high resistance connected across the grid condenser which allows electrons to leak from the grid back to the filament through the secondary coil.

grid return—A wire connecting the end of the grid coil to the filament circuit.

hand capacity—The condenser effect of the body. There is enough capacity, or condenser, effect in the body to change the tuning of a regenerative set.

megohm—A unit equaling 1,000,000 ohms.

oscillation—The surging of a current back and forth in a circuit. Generally refers to a condenser-coil circuit.

plate coil—The coil connected in the plate circuit.

pulses—Changes in strength of a direct current, as in a pulsating direct current, or the alternating-current component of a direct current.

regeneration—A process of feeding energy from the plate circuit back to the grid circuit to increase the volume of the signals.

resistance coupling—Transference of energy between circuits through a resistor-condenser circuit.

shielding—A grounded piece of metal placed between the control knob and the set in order to prevent hand capacity from affecting tuning.

signal—The voltage set up in the antenna and in the different circuits of the receiver by passing radio waves.

stage—A single amplifier tube and circuit.

transformer coupling—Transference of energy from one circuit to another by means of a transformer.

zero beat—A point at which an oscillating receiver is adjusted to resonance with an incoming signal. At this point no carrier whistle is heard.

CHAPTER 13

THE DYNAMIC LOUDSPEAKERS

In all the radio sets you have studied so far, you have used earphones to hear the music or other signals picked up by the set. You have used earphones because in many of these sets the sounds were weak and earphones fit snugly on your ears and keep out unwanted noises.

But now that you are acquainted with circuits and understand how to assemble and operate more powerful sets, you are ready to discard the earphones for loudspeakers. You cannot use the earphones in sets having much over three tubes, because the earphones will not handle the current. The sounds will be unpleasantly loud. Therefore, you will now learn the operating principles of dynamic loudspeakers and how to use them.

You will learn the following things in this chapter:

Part 1: The Purpose of the Loudspeaker
Part 2: How Dynamic Loudspeakers Are Constructed
Part 3: How the Dynamic Loudspeaker Is Connected to the Set
Part 4: How the Dynamic Loudspeaker Produces Sound
Part 5: The Quality, or Fidelity, of Sound
Part 6: How Horns and Baffles Improve Sound Quality

The new symbols used in this chapter are shown in Fig. 236.

PART 1: THE PURPOSE OF THE LOUDSPEAKER

The loudspeaker is used to produce sound loud enough to be heard at a considerable distance from the set. In a well-designed receiver the voltages on the grid of each tube and the resulting plate-current changes have followed faithfully the electrical variations in the microphone circuits at the broadcasting station.

The job of the speaker is to transform these variations in electrical energy into sound waves that are faithful reproductions of the sound waves which reached the studio microphone.

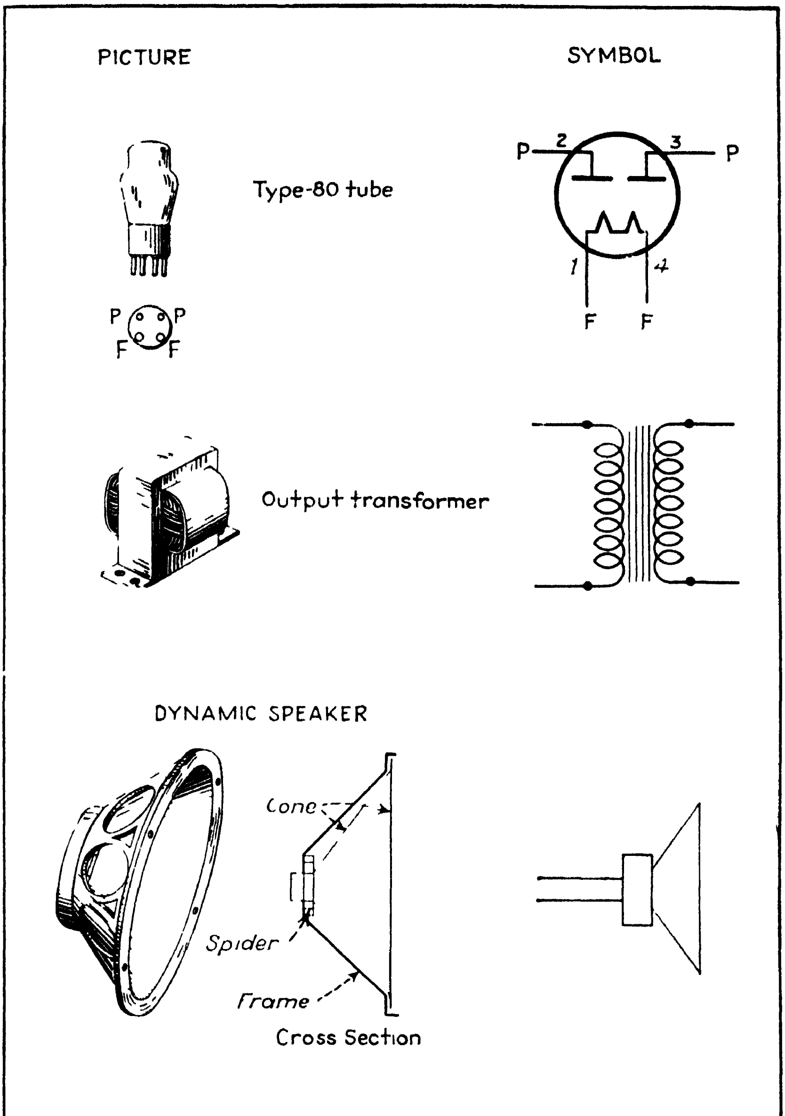


FIG. 236. These are the new symbols used in Chapter 13.

The early earphone, usable by only one or two persons, soon developed into the magnetic-type speaker. The earphone cap, with its small opening, went through its own evolution to become adapted to the distribution of louder sound volume. It was found that cupping the hands over the earphone, or setting a paper cone

on the earphone cap, seemed to make the sounds coming from it louder.

Larger coils, a larger diaphragm, and various types of horns were experimented with in attempts to improve the efficiency of the earphone as a loudspeaker.

A balanced-armature type of earphone was popular at one time. Its principle was later adapted for use in the magnetic-type loudspeaker. The two-way action of the metal armature was coupled to a diaphragm by a lever action to increase the movement of the armature. Later, the size of the coils was increased, and the diaphragm and horn were replaced by a paper cone. The result was a loudspeaker much more efficient than the earphone as a sound producer.

However, when still greater sound power was desired, a new type of speaker was developed. This was the dynamic speaker, which operated on a new principle.

PART 2: HOW DYNAMIC LOUDSPEAKERS ARE CONSTRUCTED

What is a dynamic speaker? The dynamic speaker operates, as does a meter or a motor, on the principle that a wire carrying a current will move when placed in a magnetic field. It is essentially a paper cone moved by a small coil of wire suspended in a powerful magnetic field. The result makes possible the handling of very great sound power and the production of sound of excellent fidelity and naturalness.

With this speaker, sound volumes great enough to fill large auditoriums or to operate out of doors are made possible.

Two types of dynamic speakers are in use at present: the permanent-magnet (p-m) type (see Fig. 237), in which the powerful field is provided by a permanent magnet; and the electrodynamic type, in which the magnetic field is provided by an electromagnet and a specially formed core.

As you examine different dynamic speakers, you will find that they are essentially the same in construction. (Both speaker types have the same frame, paper cone, and voice coil. They differ only in the method of producing the powerful magnetic field in which the voice coil moves.)

What is the speaker cone? The cone is made of a light, durable paper. Corrugations are pressed into the paper around the rim

near the edge of the cone. The edges of the cone are cemented to the speaker frame. These corrugations on the rim of the cone serve several purposes: They allow the cone to move freely and to

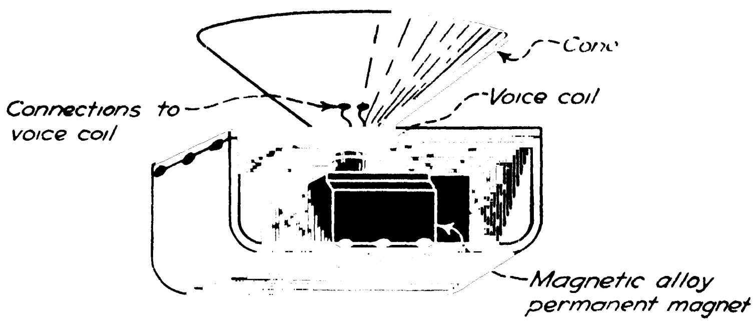


FIG. 237. The permanent-magnet (p-m) type of dynamic speaker shown here uses a piece of special alloy steel (the permanent magnet) to produce the powerful magnetic field needed for the operation of the speaker.

follow the motion produced by the weak currents flowing through the voice coil; they transmit no vibrations into the paper from the supporting frame; and they lower the resonant frequency of the cone.

What is the voice coil? A few turns of wire, called the *voice coil*, are wound on a small cylinder attached to the smaller end of the cone. The voice coil must be very light, and so small wire wound closely is usually used for the winding. From 1 to 50 turns of wire must be wound on this coil.

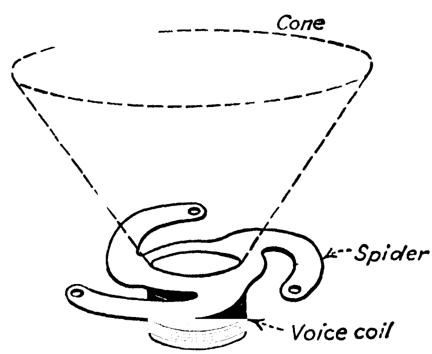


FIG. 238. The spider and voice coil of a dynamic speaker are cemented to the cone. There are many variations of the form of the spider in speakers made by different manufacturers.

What is the spider? Between the cone and the voice coil is attached a centering device called the *spider*. It is a disk of fiber or thin micarta punched to the shape shown in Fig. 238.

The spider is adjustable so that the voice coil can be centered accurately and can move freely without rubbing on the core or the disk. There are only a few thousandths of an inch clearance

between the voice coil and the core and between the voice coil and the outside iron disk or the metal frame.

Questions

1. What effect does a stiff supporting ring on the cone have upon the quality of music or other signals?
2. What effect does a heavy voice coil have upon the quality of signals reproduced?
3. About how much clearance is there between the voice coil and the core?

What is the permanent-magnet speaker field? The dynamic speaker requires for its operation a very powerful magnetic field

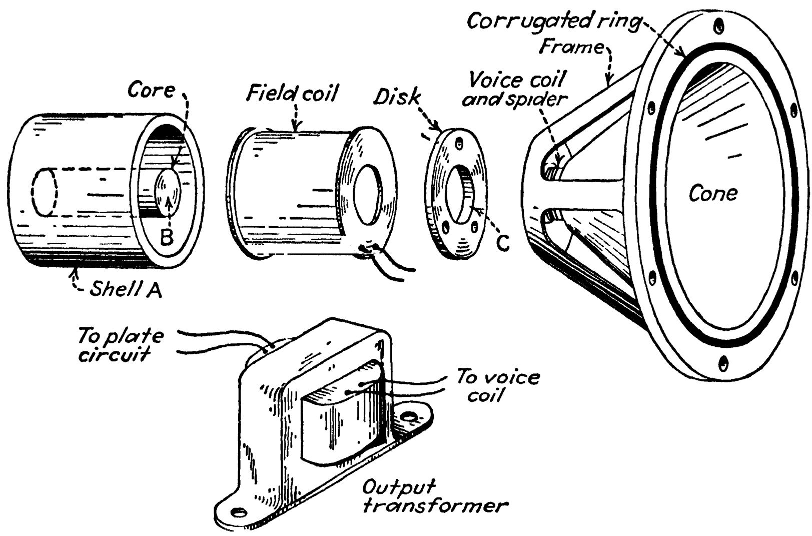


FIG. 239. An exploded view of an electrodynamic speaker.

across the space in which the voice coil hangs. The field is provided in the permanent-magnet type of speaker by a permanent magnet of special alloy, and in the electrodynamic speaker by a powerful electromagnet.

A piece of special magnetic alloy steel is welded to a soft iron frame, which carries the magnetism to the space in which the voice coil moves (see Fig. 237). The permanent magnet is made of an alloy of aluminum, nickel, cobalt, and iron which makes possible a far more powerful field and a higher flux density than do older materials. Note that the magnet and frame form a sort

of double horseshoe magnet. The upper end of the permanent magnet is formed into a circular plug which fits inside the voice coil and is one pole of the magnet. The other pole is formed by the metal frame to which the permanent magnet is welded. A hole, slightly larger than the voice coil, is formed in the frame. This leaves a narrow circular space between the frame and the central plug across which there is a very powerful magnetic field (see Figs. 237 and 239).

The speaker will be more efficient if all the voice coil is in a strong field. The magnetic lines of force produced by the field coil are concentrated across this small gap. The voice coil, placed in this gap, is in a powerful magnetic field, evenly distributed around all the coil.

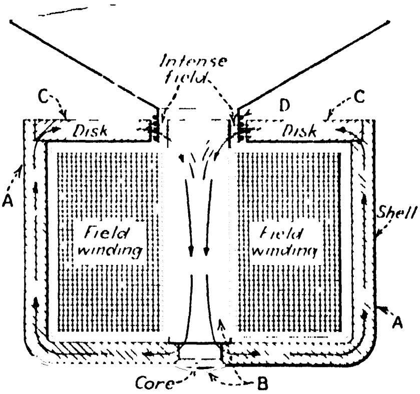


FIG. 240. A cutaway view of the field coil and magnet of an electrodynamic speaker.

What is the electrodynamic-speaker field? A very powerful magnetic field is produced when current from the power supply in the set flows in the speaker-field coil of thousands of turns of fine wire. The metal case *A* is a cup, or shell, with the main core *B* at its center (see Figs. 239 and 240). The field coil slips into the shell around the central iron core.

An iron disk *C* fits over the field coil on the top of the shell. The central core *B* fits through the hole in the disk *C*, with space for the voice coil *D* to fit between the core and the iron disk. The core, shell, disk, and winding form an electromagnet. There is an intense magnetic field across this circular space, as in the permanent-magnet dynamic speaker.

PART 3: HOW THE DYNAMIC LOUDSPEAKER IS CONNECTED TO THE SET

Examine the circuit used to connect the speaker to the receiving set, as shown in Figs. 241 and 242. They show the ends of the wires from the voice coil connected to the proper terminals on the output-transformer secondary. Instructions for making these con-

nections come with the speaker or with the output transformer The output transformer is generally mounted on the speaker.

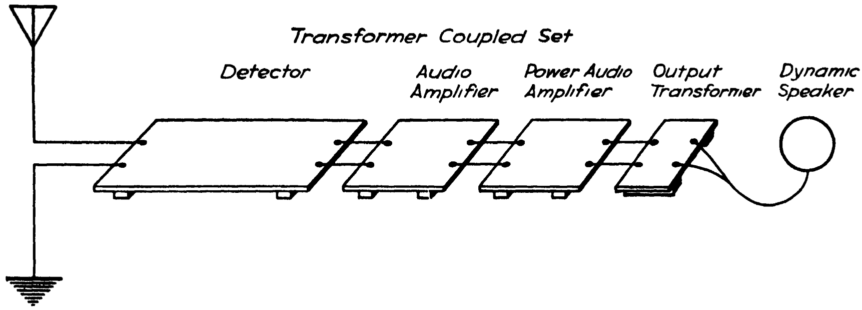


FIG. 241. An output transformer must be connected between the power audio amplifier and the dynamic speaker.

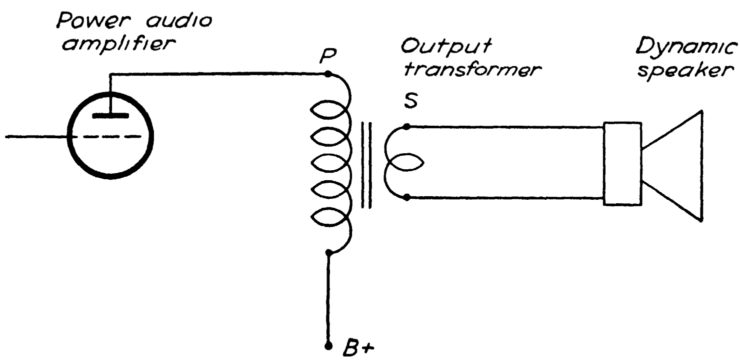


FIG. 242. The output transformer is used to couple the last power audio stage to the voice coil of the dynamic speaker.

PART 4: HOW THE DYNAMIC LOUDSPEAKER PRODUCES SOUND

How does the dynamic speaker work? There is a powerful magnetic field across the air gap. In the permanent-magnet speaker there is a steady field across the air gap, but in the electro-dynamic speaker this field exists only when the set is in operation. When the set is turned on, current from the power supply flows through the thousands of turns of the field coil and produces a powerful magnetic field in and around the coil. The core, in the shape of a horseshoe magnet, then has an intense magnetic field across the small air gap between the poles.

What causes the voice coil to move? When a current from the power-amplifier stages of the set flows through the turns of the voice coil, a magnetic field is produced around the voice coil.

A strong current flow will create magnetism that will force the voice coil either in or out of the field across the gap, depending on the direction of the current flowing through the coil (see Figs. 243 and 244).

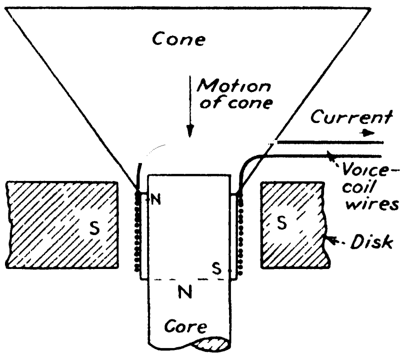


FIG. 243. When the current flows through the voice coil as shown by the arrows, the cone moves inward.

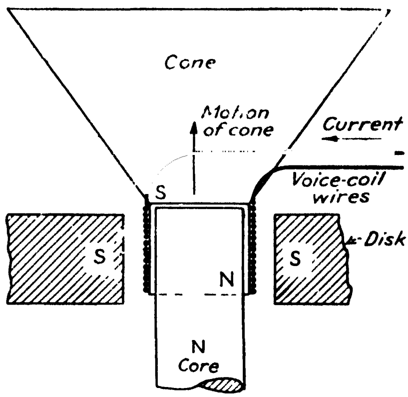


FIG. 244. When the current reverses the cone moves outward.

How does the cone produce sound? When the cone moves outward, it pushes the air near the cone outward. This produces a compression in the air which travels away from the cone.

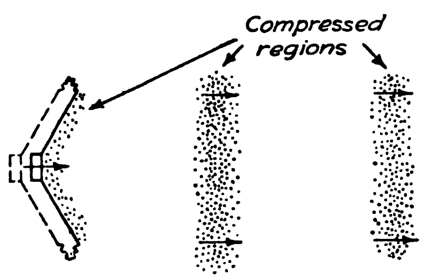


FIG. 245. As the speaker cone moves forward, it compresses the air molecules together.

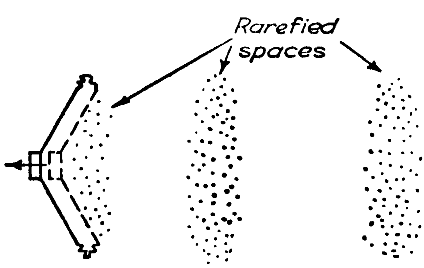


FIG. 246. As the cone moves backward, it rarefies the air and the molecules are farther apart than usual.

This also produces a rarefied area behind the cone (see Fig. 245). When the cone is pulled back, the air is momentarily rarefied in front of it (see Fig. 246). The alternate compression and rarefaction of the air produce a sound wave.

What is the source of the voice-coil driving current? The power tube in the set can be connected directly to the voice coil. But not enough current flows in the tube-plate circuit to operate the voice coil. Connected this way, the speaker would work very inefficiently if it would work at all. The reason for this is that the resistance between the filament and the plate of the power tube is around 8000 ohms. The resistance of the voice coil is from 3 to 20 ohms. To work efficiently, the plate resistance of the tube and the resistance of the coil to which it is connected must be the same.

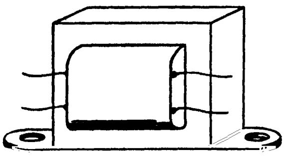


FIG. 247. The output transformer used to couple the output of a power tube to the voice coil of a dynamic speaker.

You can make the speaker operate efficiently if you connect a step-down output transformer with a ratio of about 50:1 between the plate circuit of the tube and the voice coil.

How is an output transformer constructed? In the circuit diagram, Figs. 241 and 242, a transformer is connected between the plate of the power tube and the voice coil of the speaker. It is called an *output transformer* (see Fig. 247).

Tear up a burned-out output transformer and examine its windings. Note that the primary has many turns of fine wire and that the secondary has few turns of larger wire. The core is laminated.

What is the purpose of the output transformer? *It delivers a strong current to the voice coil.* The job of the output transformer is to deliver as much power as possible from the plate circuit of the power-amplifier tube to the voice coil of the speaker, which needs much current for its operation. It is a step-down transformer, which delivers a high current at a low voltage to the speaker voice coil.

The output transformer matches impedances. The output transformer has another very important job, that of matching impedances. If you were to connect the output of the power-amplifier stage directly to the voice coil, you would get poor results. Sound would be weak because the current would be too low to operate the speaker efficiently, and also because a circuit works best when the plate resistance of the tube is approximately

the same as that of the load (the load may be the earphones, the transformer, or the resistor) to which it is connected.

The *maximum* amount of power is transferred to the speaker when the plate impedance of the tube is the same as the impedance of the transformer with the voice coil connected, and when the impedance of the voice coil matches the impedance of output transformer and tube combined.

Primary resistance is equal to the tube resistance. All of the current that flows through the tube flows through the primary of the output transformer. When the primary has a resistance equal to the tube-plate resistance, the greatest amount of useful current flows in the plate circuit.

But when the plate resistance and the load resistance are equal, there is considerable distortion. By increasing the load impedance (the impedance of the transformer primary) to twice the impedance of the tube, you arrive at a more satisfactory compromise between distortion and power output.

PART 5: THE QUALITY, OR FIDELITY, OF SOUND

In good loudspeakers the loudness, or volume, of any one frequency must not be stressed over that of any other frequency. A speaker that will reproduce overtones in music has better quality than one that kills overtones. The overtones give music its quality, or richness. The fundamental is the basic tone that is produced. *Overtones* are tones over the fundamental tones. A violin, the voice, or a good piano are all rich in overtones.

As reproduced music approaches perfect reproduction of pitch and overtones, with neither high nor low frequencies stressed, the music sounds more real. A speaker that stresses no frequencies reproduces music of *high fidelity*, or of fine quality. A good dynamic speaker will reproduce equally well all frequencies from 200 to 5000 cycles. No frequency will be stressed, nor will the volume, or loudness, of any frequency be stressed. High-fidelity speakers extend this range to from 10,000 to 15,000 cycles.

Questions

1. Describe the construction of a paper cone for loudspeakers.
2. Explain how a cone produces sound.
3. What is meant by saying that a speaker has high fidelity?

PART 6: HOW HORNS AND BAFFLES IMPROVE SOUND QUALITY

What is the purpose of a horn? The earphone is designed to send sounds directly into the ear. It works well for that purpose. But, to act as a small speaker, the earphone must have some way to set enough air molecules vibrating so that sounds can be heard in all parts of a room. (The hole in the earphone cap is so small that it sets only the air around the hole in vibration.) Cup your hands around an earphone that is connected in a receiver circuit and is lying on a table. The sounds seem louder than they do without your hands. Put a cone-shaped paper horn on the earphones, and the sounds are still louder.

The paper horn transfers the tiny vibrations of the earphone diaphragm to a gradually increasing volume of air. It also prevents scattering of the sound. It gradually spreads the vibrations so that more and more air molecules are set in vibration and its maximum sound effect is obtained. To obtain the most effective shape, formulas have been carefully worked out for the sizes of the small and the large ends of the horn, as well as for the rate at which the diameter of the horn increases. A horn of a popular and effective shape is called the *exponential horn*. You have seen such horns on portable public-address systems, for instance, those used to announce plays at football games.

In the exponential horn sound waves are set up by a powerful *driver unit*, which forces the air molecules into vibration. The horn gradually transfers the vibrations from molecule to molecule, setting larger and larger volumes of air into motion until the sound waves can be released into the surrounding air most efficiently. In this way the air vibrations of the relatively small moving part of the driver unit are coupled to the outer air

Why is a baffle used with a cone-type speaker? A slow-motion picture taken of a speaker cone would show the cone dancing back and forth, sometimes with tiny, rapid motions and at other times with huge, slow motions. The fast vibrations set up the higher pitch tones, and the slow vibrations produce the bass tones.

The cone of a powerful dynamic speaker is much larger than the diaphragm of an earphone, and it sometimes moves as much as $\frac{3}{8}$ to $\frac{1}{2}$ inch on bass notes. Obviously, an exponential horn for such a speaker would be large and awkward, particularly for use in a radio cabinet for the house.

The simplest way to bring out bass tones is to use a large, flat piece of rigid material called a *baffle* (see Fig. 248). As the speaker cone moves back and forth, it pushes air molecules in front of it to form a *compression wave* that moves outward from the speaker at 1180 feet per second (see Fig. 245).

When the cone jerks backward, it pulls some molecules with it and leaves a space where the air molecules are farther apart than usual (see Fig. 246). Air molecules move into this space, and the rarefied wave moves outward, as did the compression wave.

The distance between one compression wave and the next is the wavelength of the sound in air. A high tone, produced when the speaker cone moves rapidly back and forth, has a short wavelength. The air wave travels only a short distance before the next wave leaves the cone. These waves are close together, only a few inches apart in some cases. But for bass notes, where the cone moves slowly, the wavelength is long, sometimes over 10 feet.

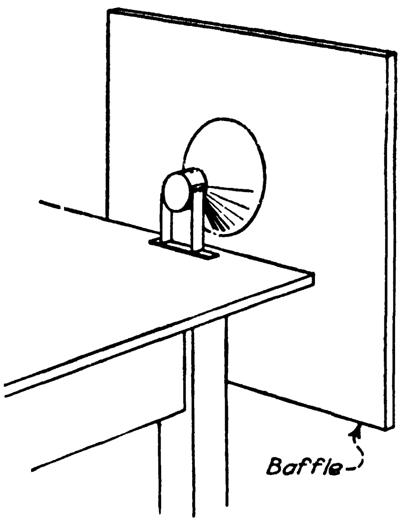


FIG. 248. Set the baffle against the speaker face. Then try several different sizes of baffles to see the effect of baffle size on the quality of the music produced by the speaker.

Where a compression wave from the front of the cone meets a compression wave from the rear of the cone, the sound is louder and clearer. But where a compression wave meets a rarefied wave, one kills the effect of the other and the sound is weakened. You can use a large, flat plate, or baffle, to force the waves produced by the rear of the cone to travel a longer distance before they reach the ear of the listener in front of the cone. The waves from the rear will thus be weakened enough to prevent their interfering with the waves from the front of the cone, which are the ones the listener wants to hear. Some of the effects of interference from the back waves can be eliminated if, at the listener's

ear, the baffle forces a compression wave from the rear and the corresponding wave from the front to meet in step, or, as the engineer would say, in phase.

You can observe the effect of baffles in a striking experiment. Cut several baffles out of heavy wallboard as follows: Make the first baffle 18 inches square, the second 36 inches square, the third 48 inches square, and, if sufficient material is available, a fourth 72 inches square. Cut a hole in the center of each for the speaker.

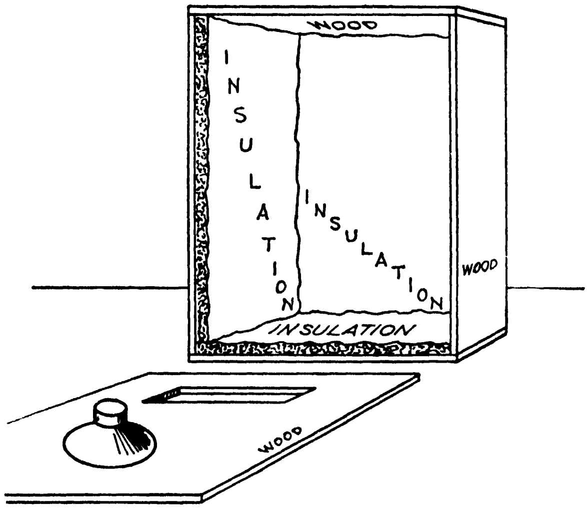


FIG. 249. This is the inside of the bass-reflex baffle. Note that there is insulation on only three sides of the inside of the box. In this way, one of each of the parallel sides is insulated.

How are cabinets used as baffles? Many forms of baffles are used. The large, flat baffle is impractical for home use because it is bulky and unsightly (see Fig. 248). Formed into an open-back box, or set cabinet, the baffle is more practical and may be very attractively designed and constructed. The design of the cabinet as a piece of furniture determines the size which will fit attractively into a living room. However, making a baffle of a cabinet reduces its effectiveness as a baffle. When the radio chassis is mounted in this type of cabinet, the resonance is usually worse for the bass tones and causes the set to sound "boomy."

What are closed-cabinet baffles? The cabinet may have the back closed to form an *infinite baffle*. The inside of this type of

cabinet is lined with an insulating material to prevent cabinet resonance, which would occur if the sound could bounce back and forth between the cabinet walls. The insulating material causes the back wave to be absorbed in the cabinet.

What are bass-reflex baffles? If you are a music lover, you will want a receiving set with a better tone quality than an ordinary set will provide. This can be had with a bass-reflex baffle,

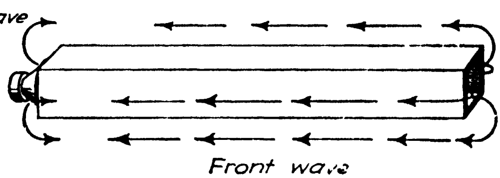


FIG. 250. A long box with the speaker set against one end makes a fairly good baffle. Its interior should be insulated. The front wave here has to travel far enough to be in phase with the back wave

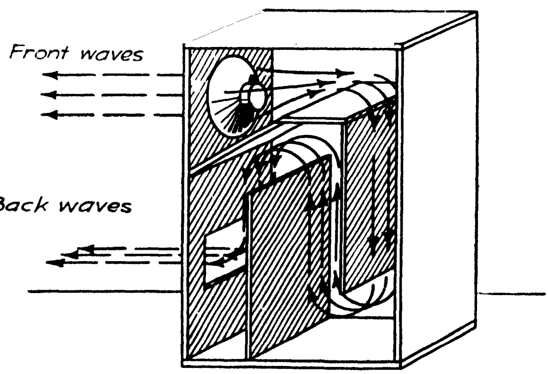


FIG. 251. The labyrinth-type baffle is built so that the back wave has to travel far enough past the different baffles to reach the air in phase with the wave from the front of the cone.

or speaker enclosure. This baffle, shown in Fig. 249, is a closed cabinet in which the speaker is mounted. It has a hole cut in the front below the speaker, so that air waves from the back of the cone can escape from the baffle enclosure and strengthen the front wave. The size of the cabinet and the size and position of the hole are so chosen that the interfering effects of the back wave are minimized. When properly proportioned, this type of cabinet produces excellent music. The radio chassis is seldom mounted in a bass-reflex cabinet.

At least three opposite sides of the interior of this baffle are covered with sound insulation.

What is the labyrinth type of baffle? These baffles are made up of folded-back passages, which are long enough to make the sound waves that produce bass tones travel the correct distance to join the front waves in the proper phase (see Figs. 250 and 251).

Questions

1. How does a horn couple the air vibrations from the driver unit to the air in a room?
2. What is the purpose of a baffle?
3. Describe several different types of speaker baffles.

Technical Terms

baffle—A large, flat surface on which the speaker is mounted. Sound waves of lower frequencies are built up by the baffle.

cone—A paper cone with a voice coil mounted on its small end. The motion of the cone produces sound waves.

dynamic speaker—A speaker which operates on the motor principle of a moving coil in a magnetic field.

electrodynamic speaker—A dynamic speaker in which an electromagnet produces the magnetic field.

field coil—The coil in the electrodynamic speaker through which current from the power supply flows to produce the magnetic field across the air gap.

magnetic speaker—A diaphragm-type speaker, or one using a moving metal armature.

output transformer—A step-down transformer connected between the last power-audio-amplifier tube and the voice coil of the dynamic speaker.

permanent-magnet dynamic speaker—A dynamic speaker in which a permanent magnet produces the field in which the voice coil moves.

spider—A flexible material fastened to the paper cone, which holds the voice coil in position in the air gap between the case and frame.

voice coil—A small coil mounted on the paper cone. Current from the set flowing through this coil causes the coil and cone to move.

CHAPTER 14

POWER SUPPLIES

Every radio receiving set and every radio transmitter has a source of power to supply the low voltage for the filaments, or heaters, in cathode-type tubes and the high-voltage direct-current B supply for the plates and screen grids of the various tubes used in the set.

The simplest type of power supply is that used in portable receiving sets. It uses replaceable long-life dry batteries for both the low-voltage filament, or heater, supply and the higher B voltages.

The popular table-model receiver operates directly from the 115-volt alternating-current supply. The heater filaments of the several tubes in the circuit are connected in series and then are connected directly across the 115-volt alternating-current line. The direct current for the B supply is obtained by rectifying and filtering the 115-volt alternating current into a direct current of slightly lower voltage. The alternating-current direct-current type of set is provided with a switch so that the set can also be used on batteries or be connected to an alternating-current line of 115 volts.

The larger sets, the console models, use tubes which operate on higher plate voltages so that greater output may be had. They use a transformer to supply the different voltages needed to operate the set. The transformer has several secondaries. One or more secondaries supply the low heater voltages for the different tubes, and another secondary supplies high voltage alternating current which must be changed to a direct current for the B supply. This is done by the use of a rectifier tube and a filter system which delivers pure direct current to the set.

Transmitters also use the latter type of power supply to furnish the high direct-current plate voltages needed by the special transmitter tubes.

Automobile radios use still another type of power supply, which is a variation of the transformer type. Their filaments are supplied directly by the 6-volt storage battery. But because a transformer will not operate on the pure direct current from the car battery, a vibrator is connected in the primary circuit to provide a pulsating direct current, which will operate the transformer. The high-voltage output is then rectified and filtered, as is done in the console-type set.

Each type of power supply has some sort of voltage-distributing system consisting of one or more resistors which reduce the high B voltage from the B batteries or from the power supply unit to the proper value for the different tube elements.

You will learn the following things in this chapter:

Part 1: How the Vacuum Tube Rectifies an Alternating Current
Part 2: What Parts Are Used in a Transformer-type Power Supply
Part 3: How to Build an Alternating-current-receiver Power Supply Using a Type-80 Tube
Part 4: How the Transformerless Power Supply Can Be Wired
Part 5: How the Vibrator Type of Power Supply Is Wired

PART 1: HOW THE VACUUM TUBE RECTIFIES AN ALTERNATING CURRENT

Experiment to Show Rectification

The vacuum tube has many uses. You have already used it as a detector and as an amplifier. In both of these capacities you saw how it operated as a very sensitive electrical valve in which a few electrons on its grid controlled the flow of a strong plate current.

Now study again the experiment in which you learned that electrons in a vacuum tube would flow only from filament to plate (see Chapter 7). In the experiment you are about to do, you will begin the study of another practical application of this tube characteristic, the one-way flow of electrons through the vacuum tube. This characteristic is called *rectification.*

How to Wire the Experiment

Step 1. Use the set board and 1LE3 tube shown in Figs. 252 and 253.

Step 2. Connect the tube plate to the grid by running a wire from the input grid post to the output plate post.

Step 3. Connect neon tube *A* to the output posts and neon tube *B* to the B-plus and B-minus terminals of the set board.

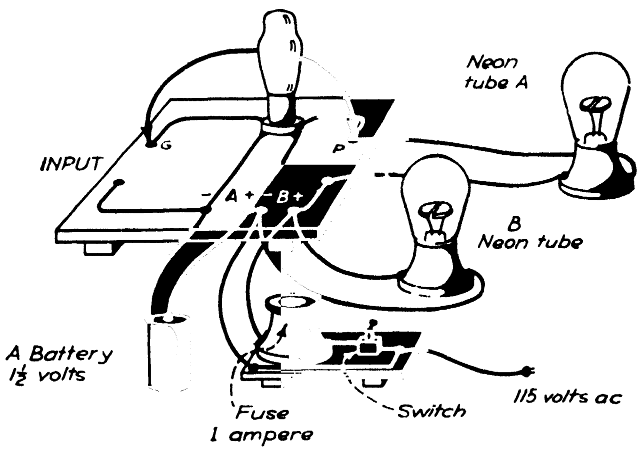


FIG. 252. Connect the tube this way to show how a triode tube can be made to rectify. The glow of the neon tube shows rectification.

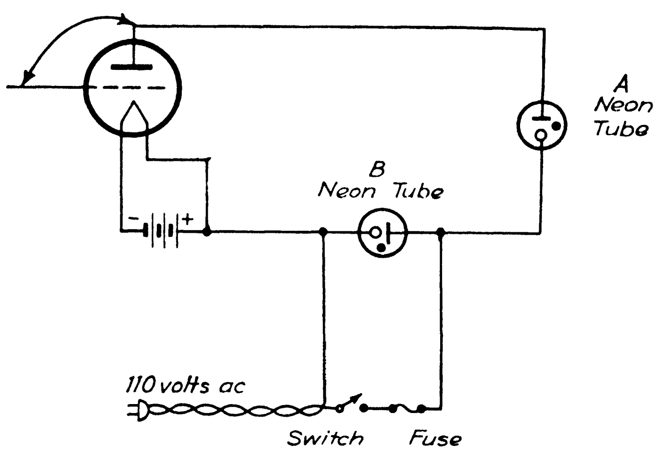


FIG. 253. Connect the tube board this way to demonstrate how the triode will rectify. The way the neon tube glows shows when rectification takes place.

Step 4. Use the 115-volt alternating-current source in place of the B battery. Also, connect wires from a 1-ampere fuse and switch mounted on a board to the B-plus and B-minus terminals of the set board. The fuse is a protection against short circuits.

Caution. Connect the wires to the set *before* you plug the cord into the 115-volt alternating-current outlet.

How to Operate the Experiment

Heat the tube filament by connecting the A battery. Then plug in the cord to the 115-volt alternating-current outlet, and turn on the switch. Both neon tubes should glow.

Compare the glow of one tube with the other. Does one or do both plates glow?

Why It Works

What is the neon-tube action? The neon tube is handy to test for the type of current flowing in a circuit. When a neon tube is connected across wires carrying an alternating current, both plates of the tube will glow. But when a neon tube is connected across a circuit in which a direct current is flowing, a current flows in only one direction, and only one plate glows.

In neon tube *B*, which is connected across the alternating-current line at the B terminals on the board, both plates glow, and without a noticeable flicker. But in neon tube *A*, which is connected across the output posts, only one plate of the neon tube glows, and that with a noticeable flicker.

How does the neon tube show rectification? Both plates glow in the neon tube *B* connected to the wires from the 115-volt alternating-current line. This shows that the line supplies an alternating voltage and that electrons were forced first on one plate and then on the other.

Then why does only one plate glow in neon tube *A*, which is connected in the plate circuit? The alternating current in the line drives electrons toward the plate of the vacuum tube on one alternation of the cycle; this makes the plate of the vacuum tube more negative than the filament. No current flows through the vacuum tube, because electrons ordinarily will not leave a cold metal surface such as the tube plate.

However, on the next alternation of the alternating-current cycle, the current reverses and electrons are pulled off the plate of the vacuum tube, which then becomes more positive than the filament. The positive plate pulls electrons from the space charge around the filament, current flows through the tube, and one plate of the neon tube glows.

The flickering glow of this one plate shows that a pulsating direct current is flowing in the circuit of the vacuum tube.

How can you see a wave picture of rectification? You can see a wave picture of what happens in this circuit by using the oscillo-

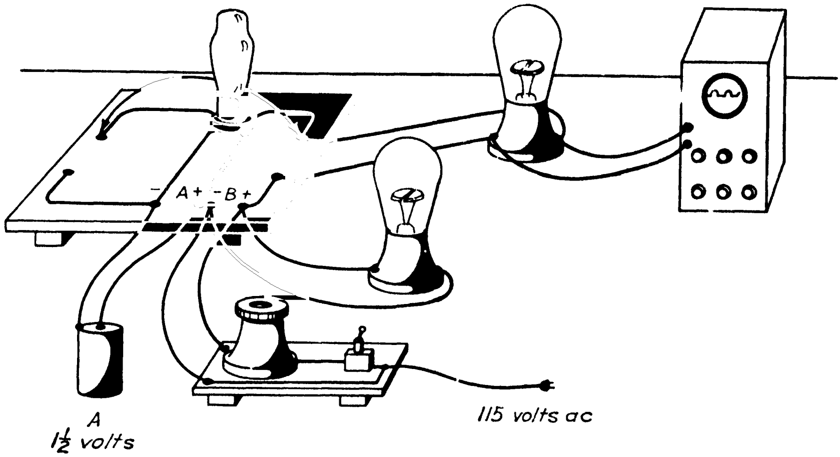


FIG. 254. Connect the oscilloscope as shown here to see a wave picture of a rectified alternating current. Touch the test points to the neon-tube connections to show the wave shape of the rectified alternating current.

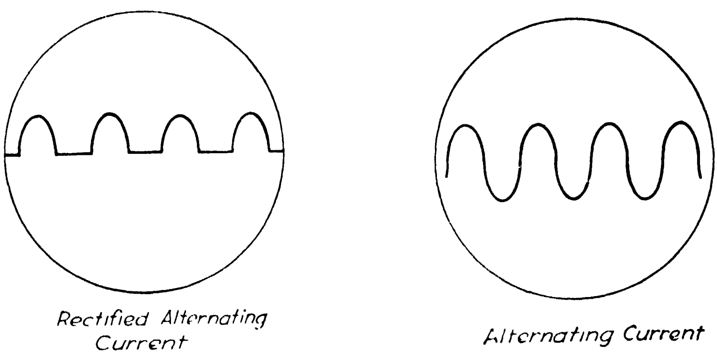


FIG. 255. Wave pictures of an alternating current and of the same current after it has been rectified. The rectified current flowed only one way through the tube.

scope. Attach test points to the two V-plate terminals of the oscilloscope (see Fig. 254).

First, touch the test points to the two B terminals on the tube board. Adjust the scope controls so that you can see the alternating-current sine wave like the one at the right in Fig. 255.

Second, move the test points to the two sides of neon tube *B* in the plate circuit. You will now see that only half the wave remains (see the left picture in Fig. 255). The wave will be either above or below the time line, depending on the way you hold the test points on the connections to the neon tube.

This experiment shows you that a current of electrons can flow in only one direction through the vacuum tube.

Questions

1. Name the essential parts in a standard power-supply unit.
2. How does the neon tube prove that the current is flowing in only one direction through the rectifier tube?
3. Draw wave pictures of an alternating current, a pulsating direct current, a steady direct current, half-wave rectification, and full-wave rectification.

PART 2: WHAT PARTS ARE USED IN A TRANSFORMER-TYPE POWER SUPPLY

You have already learned the principles of the transformer, of the condenser, and of the rectifying action of a tube. However, you have yet to become acquainted with the transformer used to furnish power for the whole radio set and with the condensers and choke coils used in the filter to smooth the pulsating direct current from the rectifier tube into a steady, high-voltage direct current for the different tube plate circuits in your set.

An excellent way to become acquainted with transformers, condensers, and chokes is to obtain burned-out ones and tear them apart. You can then learn how they are made.

Build or examine the set-board power-supply unit shown in Fig. 256. Note the different parts, or *components*, used in the unit. Also follow the schematic diagram in Fig. 257 to help you understand the circuit.

What are the units of the circuit? This circuit has several parts, or divisions, each with a definite job to do. These are the voltage-changing unit, the rectifying unit, the filter unit, the voltage-distributing unit, and the supply for heater voltages. You can see these different divisions in the block diagram in Fig. 258 and learn what each of them does. Examine this block diagram, and compare it to the circuit shown in Fig. 257.

Suppose you start at the power line and examine each part.

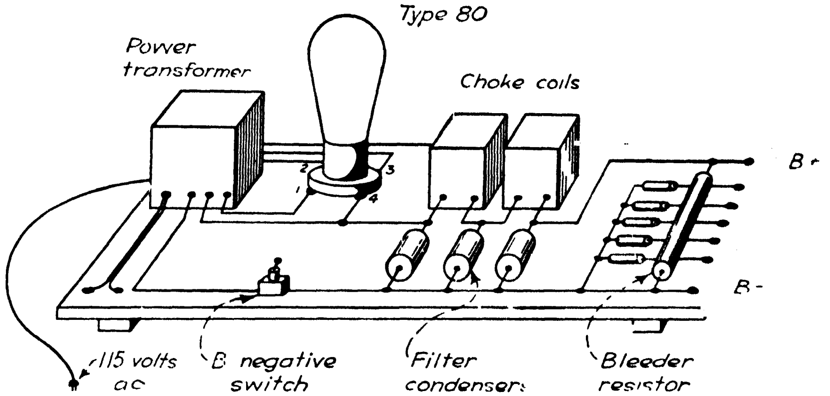


FIG. 256. The position of the parts on the power-supply board. Note a 5Y3 tube can be used but it will require an octal socket in place of the four-prong socket shown here.

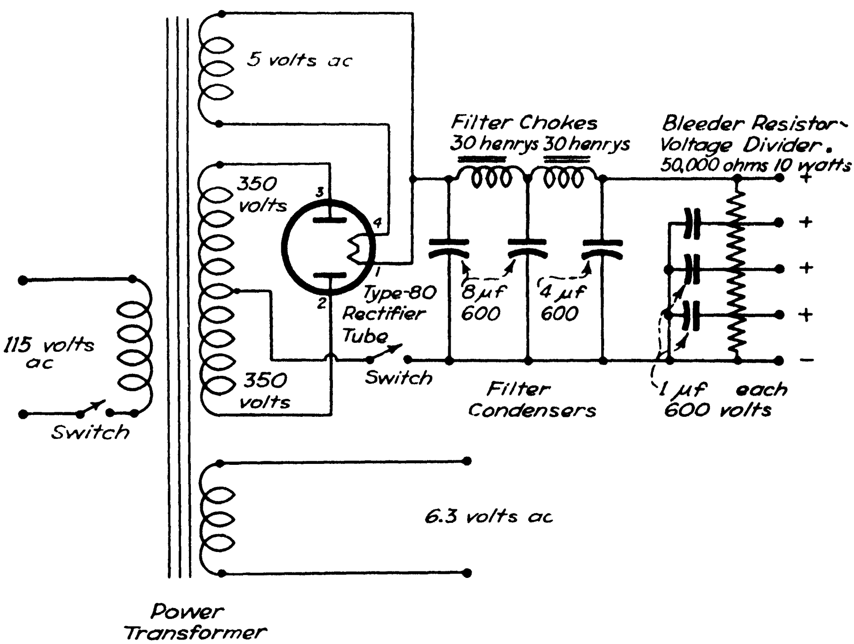


FIG. 257. The schematic diagram of the power supply.

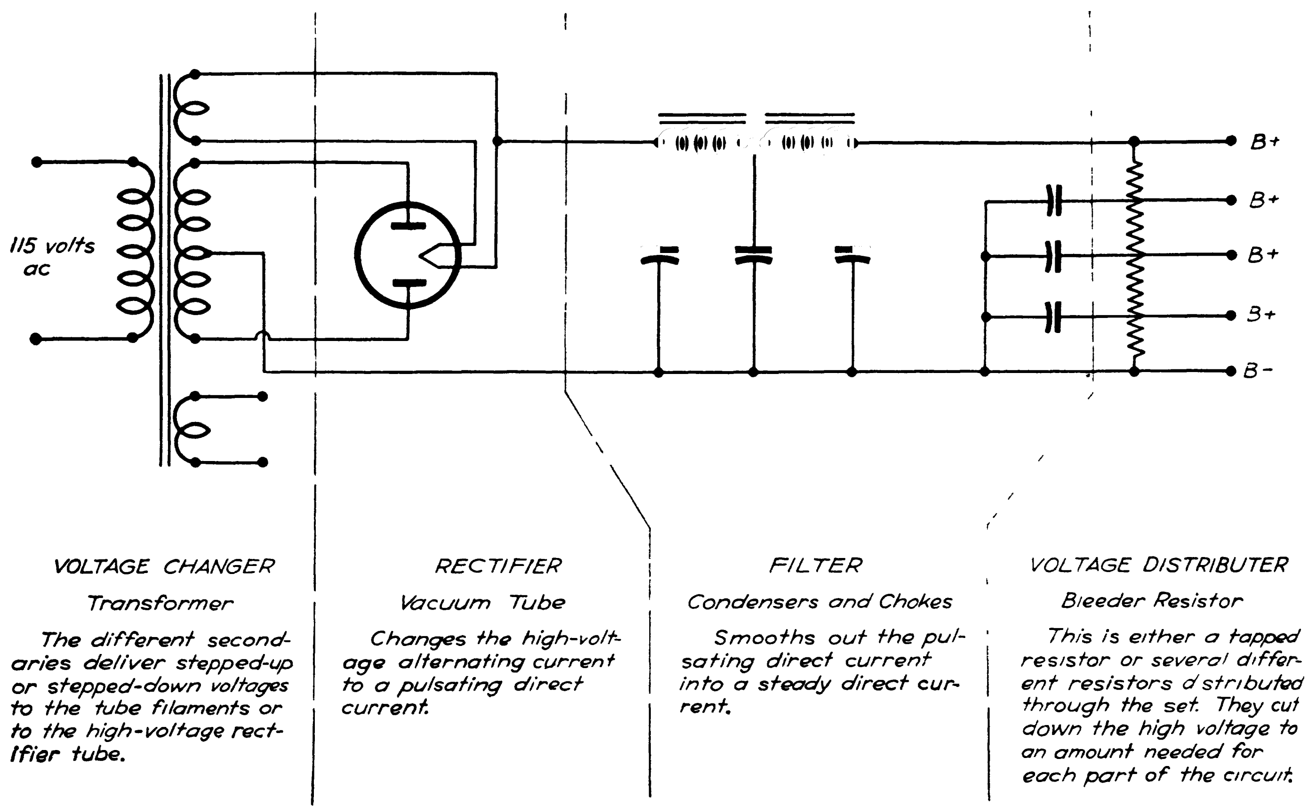


FIG. 258. Sections of the power-supply circuit.

Examine a good power transformer. The schematic diagrams in Figs. 257 and 258 show that the alternating-current line connects to the primary of the power transformer.

Examine a good unshielded iron-core power transformer. Some transformers are enclosed in a metal shield to keep the constantly changing magnetic field around the windings from inducing currents in nearby wires. Such action causes an unpleasant hum to interfere with the signals in your earphones or loudspeaker.

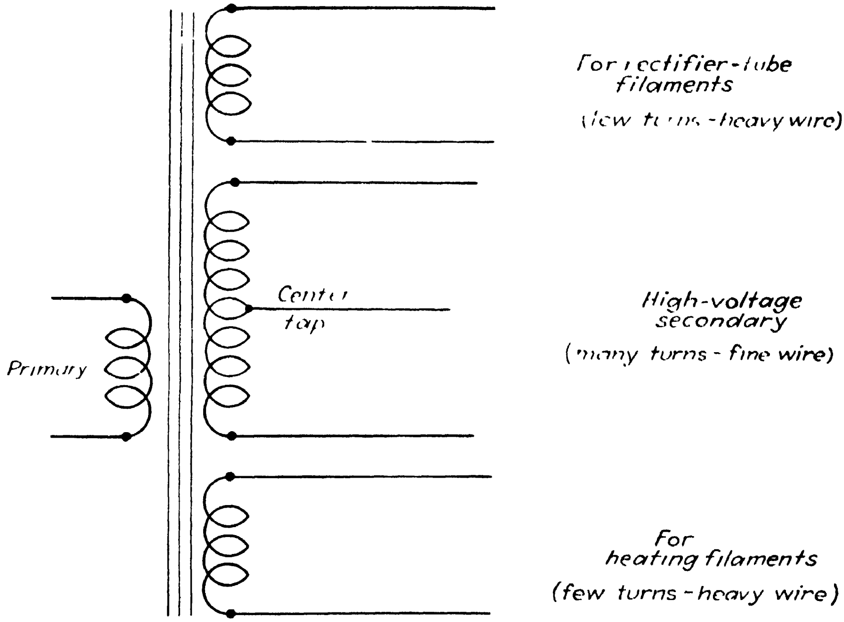


FIG. 259. Use a copy of this diagram to show wire sizes, number of turns on each secondary, and output voltage as you tear up a burned-out transformer.

How can you identify the different windings? The ends of each winding are brought out to metal soldering lugs; or terminals, to which circuit wires can be attached. Make a diagram of these different coils, and name each as in Fig. 259. Copy the diagram furnished by the manufacturer of the transformer, if it is available.

The size of the wire in the winding is a clue to the job this winding does. Large wire is used when a heavy current flows in a winding, such as the one used to heat the tube filaments; fine wire is used in the high-voltage secondary, in which a small current flows. Many turns are used in high-voltage windings; few turns

are used in low-voltage windings. Flexible insulated wires are brought out from the ends of the high-voltage winding and its center to the soldering lugs. The heavy wire of the low-voltage windings is connected directly to the lugs.

Test each winding with an ohmmeter. You can also tell something about each winding by measuring its resistance with an ohmmeter. First identify the high-voltage secondary. It will have the smallest wire, the greatest number of turns, and, therefore the highest resistance. Write the value of its resistance on your diagram.

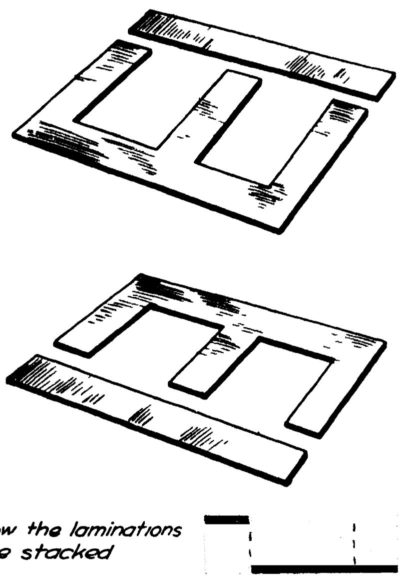


FIG. 260. Here are two laminations punched out of special transformer iron used for the transformer core. Note the way they are stacked.

The primary winding will have medium resistance. The filament windings, which are wound with few turns of heavy wire, will have the lowest resistance. Look up in the Radio-tube Characteristics Charts the amount of current used by the rectifier-tube filament. It is 2 amperes for either the type-80M or type-5Y3GT tube. Relatively large wire, such as No. 17, is needed to carry this much current without heating. The other filament winding must supply the filament-heating current for all the tubes in the set with which the power-supply unit will be used. If, for instance, your set uses two 6F6 audio-power-amplifier tubes, the filament-heating current will be 0.7 and 0.7, or 1.4, amperes. Number 17 wire could be used for such a winding.

Tear up burned-out power transformer. Obtain several questionable or burned-out power transformers and test them to find out which windings are defective. Any winding may burn out when too much current flows through it. The winding heats up, the insulation burns off, and the wires touch each other. More current then flows, and the heat rapidly increases until the wires burn in two or the fuse blows out.

Thus the test of a defective winding may show either a short circuit or an open circuit. The winding has almost no resistance if the wires touch each other or are shorted. It has infinite resistance if the wires are burned in two and the winding is open.

Remove and examine the core. Pry apart two of the thin outer steel sheets of the core. Pull out a few of these sheets with pliers, and the rest will come out easily. Note the shape of the laminations and the way they are stacked together (see Fig. 260). One sheet of the core is a *lamination.*

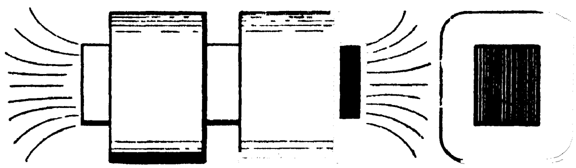


FIG. 261. Much of the magnetism is lost at the ends of an open-core type of transformer.

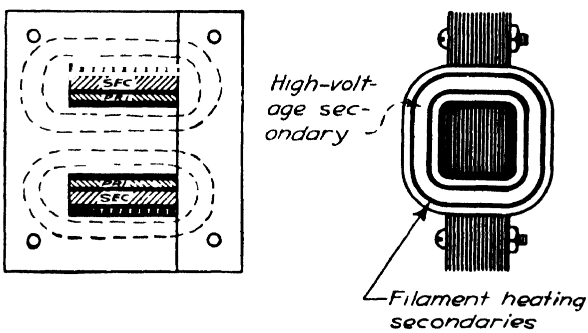


FIG. 262. In this closed core transformer, little magnetism is lost because there is a complete path for the magnetism through and around the windings.

Why laminations are used. The power transformer changes both the voltage and current from the power line to values that can be used in your radio set. It transfers much more power than did the air-core radio-frequency transformer that you used in your detector circuit. You learned when you studied meters that iron was a much better carrier of magnetism than air. The different coils of the power transformer are wound around a heavy iron core, so that they will operate in a very strong magnetic field. The core is shaped so that it has a continuous iron path which allows the loss of very little magnetism (see Figs. 261 and 262).

The core is made of thin laminations so that *core losses*, produced by *eddy currents*, will be very small. Eddy currents are induced in the iron of the core by the rapid changes of the magnetic flux in it. This produces heat in the core. By making the core of thin metal sheets, insulated from each other by shellac or other compounds, the eddy currents and the heat they generate are kept quite small. The shape of the laminations permits easy stacking during assembly. Now examine the windings.

Remove the filament windings. Take off the filament windings and count the number of turns on each. Also measure the wire size with a wire gage or a micrometer. Print the size of the wire and the number of turns on your diagram of the windings.

Remove the high-voltage secondary winding. Find the total number of turns on the high-voltage secondary by counting the number of turns on the top layer and then cutting away the insulation so that you can estimate the number of layers. This winding has more turns than any of the others. Measure the size of the wire. Print the wire size and the number of turns on your diagram.

Remove the primary. Sometimes the primary is wound over the secondaries, but it generally is wound next to the core. Unwind it, count the turns, and measure the wire size. Record the information on your diagram.

Why are step-up and step-down transformers used? A transformer is an efficient device for stepping up the supply-line voltage to the high plate voltages that you need and for stepping down the voltage for a tube filament, or heater.

The transformer can be built to have better than 95 per cent efficiency. The low magnetic loss of the closed core and the selection of high-grade materials both contribute to this high efficiency.

You can readily see the step-up and step-down action of a transformer by connecting a low-voltage supply to the primary of a power transformer similar to the one you tore up. Use 10 volts on the primary so that you can measure the different output voltages of the secondary with little danger of shock. Use a step-down laboratory transformer to get the 10 volts for the primary.

Measure the output voltage of each winding with a good high-resistance alternating-current voltmeter. You will need a 0 to 5 alternating-current voltmeter for measuring the filament voltages

and a 0 to 150 alternating-current voltmeter for measuring the output of the high-voltage secondary.

Make a second diagram similar to the one shown in Fig. 259, and write opposite each winding the voltage you measured across it. (You will probably be unable to measure accurately the very small voltages from the low-voltage secondaries, but you will at least observe that they are very small.) Now write below these voltages the number of turns that you counted on the windings.

Find the turns-per-volt ratio. The *turns-per-volt ratio* is useful in studying transformers. From it you can easily design a transformer for certain definite voltages when making your own set. You might need such a transformer for heating the filaments of tubes in a transmitter. You could get the desired voltage by rewinding an old power transformer. Find the turns-per-volt ratio of the primary by dividing the number of turns on the primary by the voltage normally connected to it.

If the transformer that you unwound had 385 turns on its primary and it was designed for a 115-volt supply, the ratio for the primary would be 385 divided by 115, or $3\frac{1}{3}$ turns per volt.

But suppose that you do not wish to unwind the primary, which may not be burned out. It often happens that only the high-voltage secondary burns out and the rest of the windings may be used.

You can find the turns-per-volt ratio for a secondary by winding a temporary secondary of 10 turns over a primary winding. (This should be done on a transformer which has had the burned-out secondary and the low-voltage secondaries removed.) Then when you connect 115 volts of alternating current to the primary, a voltage will be induced in the temporary secondary. Measure this voltage. Suppose it is 5 volts. You will then know that the turns-per-volt ratio of the temporary secondary is 10 divided by 5, or two turns per volt.

You can now remove the temporary secondary, add suitable insulation, and wind on the correct number of turns to get any desired voltage. You will find this information useful for winding filament-heating transformers to use in transmitters or for special experiments you may want to perform.

How is this ratio used? If you know the number of turns on the high-voltage secondary of a transformer, you can work out the voltage that the transformer will deliver once you know the pri-

mary voltage and the number of primary turns. Or if you know the secondary voltage that is needed, you can wind the proper number of turns on the secondary.

In a transformer the secondary voltage equals approximately the primary voltage times the turns ratio. So a turns ratio of 3 means that with 115 volts on the primary, the output voltage across the two secondary windings will be about 350 volts. (In the power-supply circuit in Fig. 257 you will find that each secondary delivers voltage to one of the two plates of the rectifier tube.)

Small wire is used on the high-voltage secondary winding, because little current flows in this winding.

Rule. When you step up the voltage, you step down the current.

While you cannot measure accurately the voltage across the low-voltage secondaries with 10 volts on the primary, you will find that in practice the step-down ratio still holds true. With 115 volts on the primary, you should have about 18 turns of wire on the 6.3-volt filament winding. Check this number with the number in the table you made when you tore up the old transformer.

On the low-voltage secondaries the wire is large and there are but few turns in the winding. Here the voltage has been stepped down while the current has been stepped up, thus requiring wire of larger diameter to carry the increased current.

Rule. When you step down the voltage, you step up the current.

Questions

1. How can you tell when a coil in the transformer is burned out?
2. State several ways to distinguish the primary of coils used in radio circuits from the secondary.
3. Why are transformer cores made up of flat plates?
4. Define *magnetic flux*.
5. The primary of a transformer is connected to a 115-volt line. This primary has 100 turns. How many turns would you put on a secondary which is connected to the filaments of two 6F6 power tubes that are connected in parallel?
6. How many turns would you put on a secondary which has to deliver 180 volts? What size of wire would you use if this coil drew 1 ampere?

Examine the rectifier tube. The tubes used to change the high-voltage alternating current into a pulsating direct current are generally full-wave rectifiers. They are designed to handle about 350 volts from plate to filament and from 70 to 125 milliamperes of current. They are built in either glass or metal envelopes.

One of the tubes used for this purpose is the type 80, which is a glass tube with a four-prong base. In it are two plates and two filaments.

Other types of rectifier tubes are similar in construction and have octal bases. Examples of these tubes are the 5Y3, the 5Y4, and the 6X5. All have the octal base, but the elements are brought out to different connections.

These rectifier tubes have heavy filaments made of wide, flat wire that is oxide coated to give good electron emission. The plates are large and are blackened to improve heat radiation. These tubes run hot and so are installed in a set at a point where this heat can be radiated safely.

Later in this chapter you will read the detailed description of how a rectifier tube is used to rectify the alternating current in a power supply.

What condensers are used in the power-supply filter? The condensers used in the power-supply filter must have a large capacity because of the low frequency of the pulsating direct current (120 pulses per second) flowing in and out of them. They are normally of 2, 4, or 8 microfarads capacity.

The electrolytic condenser is used in low-voltage power supplies because of its high capacity and relatively small size. An electrolytic condenser consists of two thin aluminum sheets separated by gauze soaked with a chemical called the *electrolyte*, which forms a microscopically thin dielectric film on one aluminum sheet. The film is a good insulator and, because it is so thin, gives the condenser high capacity with plates of relatively small area.

Examine an electrolytic filter condenser. Examine a burned-out electrolytic condenser. Note first that the connections to it are marked plus and minus. Electrolytic condensers must be connected correctly in the circuit. If reversed, they will burn out. Note the type of container in which the condenser is enclosed. Tear it up and examine the metal and the dielectric.

Why it works? The aluminum plate on which the dielectric film is formed is the positive plate. The negative terminal is connected to the other plate. This type of condenser will only operate on a pulsating direct current. The dielectric film prevents current from flowing in one direction, but a current can flow in the other direction through the film. However, if a current is

allowed to flow in this direction, it soon develops heat and ruins the condenser. Excessive voltage will also destroy the condenser, for it may puncture the film.

Connect several of these condensers in series, and charge them by momentarily touching the ends of the wires to the high-voltage taps on the power supply. Now discharge them by touching the wires together. Observe the size of the spark that you get from the series connection. Now connect the condensers in parallel, and again charge them from the power supply. Then discharge them as before. Observe that the spark is now much larger, because the capacity of condensers when connected in parallel is much greater than their capacity when connected in series.

In selecting a condenser, consider its working voltage. Almost every condenser has marked on the case its working voltage and its capacity (in microfarads). The working voltage is the same as that measured by a meter. It is 0.707 ($\frac{707}{1000}$) of the highest, or peak, voltage of the alternating current or of the peak of the rectified current.

It pays to use a condenser that has a higher working voltage than your power supply will deliver, because this gives you a margin of safety. You will be less apt to burn out such condensers during experiments with your different sets.

Voltage surges cause burnouts. These surges may occur while the rectifier tube is warming up, or perhaps during an experiment as a result of an accidental short circuit. The resulting rushes of current set up excessive voltage surges which may burn out the condenser. A condenser with a higher working voltage will stand these temporary surges safely.

Compare peak voltage and effective voltage. The sine wave of an alternating voltage in Fig. 263 shows both the peak voltage and the effective voltage. Note that the line drawn through the sine curve, $\frac{707}{1000}$, or approximately $\frac{7}{10}$, of its total height, is the *effective voltage*. This is the voltage that is indicated on a voltmeter. The alternating current reaches a higher peak value than this, but it remains at this peak for only a moment, so that the effect on the equipment in the circuit is the same as if a lower steady voltage were at work. Meters read the effective voltage, but it is the peak voltage that burns out the condenser. An example will make this clear.

When you use an alternating-current meter to measure the alternating-current voltage across the primary of the power transformer and find it to be 70 volts, you are measuring the effective voltage. A special peak voltmeter would show that the peak voltage is 100 when the effective, or working, voltage is 70.

How is peak voltage found when you know working voltage? You know that 350 is approximately $\frac{7}{10}$ of peak voltage, and so

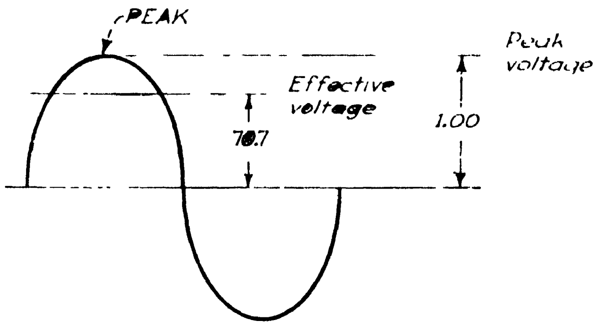


FIG. 263. You have two voltages to deal with when handling filter condensers. One is the *peak* voltage which burns out a condenser unless you allow for it. The effective voltage is that voltage measured by the meter. Your condensers must be rated for the peak voltage.

to find the peak voltage, which would be $\frac{10}{10}$, use the following process:

Step 1. Find $\frac{1}{10}$ of the peak voltage.

Since

$$\frac{7}{10} = 350$$

Therefore,

$$\frac{1}{10} = \frac{350}{7}$$
$$= 50$$

Step 2. Then multiply 50, or $\frac{1}{10}$ of peak voltage, by 10.

$$50 \times 10 = 500$$

Therefore, the approximate peak voltage is 500. You can find the accurate peak voltage by using $\frac{707}{1000}$ in place of $\frac{7}{10}$.

If the alternating-current output across the high-voltage second-

ary of your power transformer is 350 volts, you must multiply this number by $\frac{1000}{707}$, or 1.41, to find the peak voltage.

$$\text{Effective volts} \times 1.41 = \text{peak voltage}$$
$$350 \times 1.41 = 493.50, \text{ peak voltage}$$

Select a condenser with a working voltage of 600 volts to be safely used in this circuit.

Examine a choke coil. Tear apart a burned-out choke coil to learn how it is made. The choke coil has one winding on an iron core. Like the power transformer, the choke coil may be enclosed in a sheet-steel shell to protect the windings and to reduce stray fields.

Note that there is a narrow air gap left in the core. This air gap prevents the core from becoming saturated with magnetic flux and consequently losing part of its choking action.

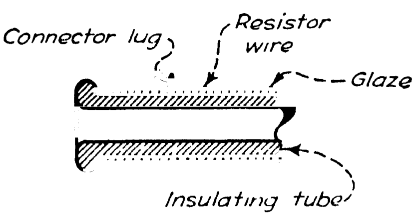


FIG. 264. This cross section shows the construction of the bleeder resistor.

The size of the wire depends on the amount of current the choke must carry.

The choke-coil theory was explained in Part 4 of Chapter 10.

How are the bleeder resistors made and used? The type of bleeder used in this laboratory power supply is seldom used in the later models of radio sets. But since it is found in some form in all radio equipment, it will be described here.

The bleeder resistor has a fine resistance wire wound on a porcelain tube. The wire and tube are covered by a burned-on glaze that holds the wire and the connection lugs in place and protects the wires from breakage (see Fig. 264).

This type of insulator will stand much current and heat. It heats up in operation, and so it is mounted on the set where air movement can carry away the heat. Taps placed along this resistor allow different plate and screen voltages to be obtained for the tubes in your set.

Most of the recent sets use individual resistors at each tube socket to give the desired voltage. Such resistors are made of compressed graphite or, occasionally, are wire-wound. The size,

length, and diameter of the former type, as well as the amount of inert material in the graphite, determine its working resistance.

Now assemble these parts into a complete power-supply unit.

Questions

1. Does an electrolytic condenser work satisfactorily on an alternating current?
2. Define *effective voltage.*
3. Why is it necessary to consider peak voltage when selecting a condenser?
4. What is the difference in the construction of a choke coil and a transformer?

PART 3: HOW TO BUILD AN ALTERNATING-CURRENT-RECEIVER POWER SUPPLY USING A TYPE-80 TUBE

How to Build the Power Supply

The Power Transformer. Use a heavy-duty power transformer with a high-voltage secondary capable of delivering 350 volts on each side of the center tap and 125 milliamperes of current. There should also be a secondary delivering 5 volts for the heater of the type-80 tube and another delivering 6.3 volts for the filaments of the detector and amplifier tubes.

Be sure that you purchase a power transformer capable of supplying the filament and plate currents required by the tubes that you will be using in your set.

The Rectifier Tube. Use a type-80 rectifier tube. Place a four-prong socket in the position shown in Fig. 256 (page 305). The method you use in mounting the different parts on the board will depend on the parts which you use.

Condensers. Use three dry electrolytic condensers, one of 4 microfarads capacity and two of 8 microfarads capacity, each with a working voltage of at least 600 volts. Condensers with lower voltage ratings will burn out too quickly.

The Choke Coils. Use two 30-henry choke coils. The choke coils must carry 125 milliamperes of current. Remember that you may want to put more tubes on the power supply than normally, so get a choke that is large enough to carry the heaviest current you may use.

The Bleeder Resistor. A power supply to be used for experimental work should have several high-voltage direct-current terminals. If several fixed direct-current voltages are needed, the bleeder may be a 25-watt tapped fixed resistor of 25,000 to 50,000

Westinghouse Electric Corporation

BIG BROADCASTING TUBES

Four 50,000-watt tubes used in radio broadcasting Two of these big air-cooled tubes at this radio station are spares By simply pushing a button the operator can put them into service without the removal of the defective tube or the interruption of transmission

ohms resistance, connected across the output of the filters. If no bleeder resistor is used, the filter condensers are apt to burn out when no load is connected to the power supply.

Arrangement of the Parts. Arrange the parts for the experimental power supply as shown in Fig. 256, breadboard style; but if the power supply is for use in a set, mount the parts on a metal chassis in any convenient fashion.

How to Wire the Circuit

Figure 257 (page 305) shows the wiring of the various parts of this power-supply unit. Wires from the ends of the high-voltage secondary to the plates of the type-80 tube must be well insulated. They have about 700 volts among them. Connect an off-and-on switch in the negative lead to the filter.

Questions

1. How many condensers should be used in the power supply?
2. What size of condensers should be used?
3. Should the filter condensers be rated to withstand the output voltage or the transformer voltage of the power supply?
4. How many choke coils should be used?
5. How many milliamperes of current should the wires of the choke coil be able to carry?

How It Works

The power transformer. The 115-volt alternating current surging through the primary of the power transformer induces an alternating voltage in each secondary winding (see Fig. 257). An alternating voltage of 5 volts induced in one secondary heats the filaments of the type-80 tube, causing them to give off electrons.

An alternating current of low voltage (6.3) induced in the other low-voltage secondary is used to heat the detector and amplifier-tube filaments on the radio set.

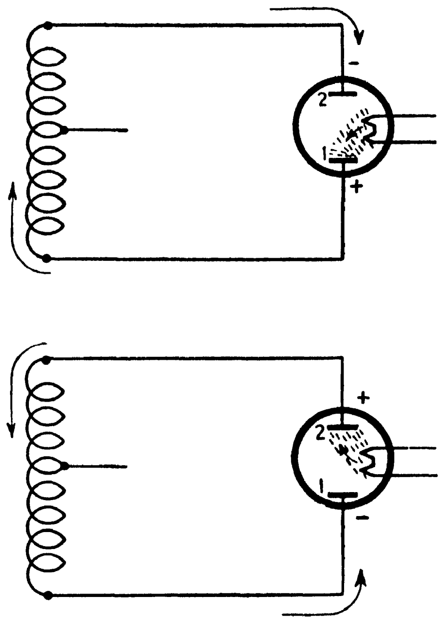
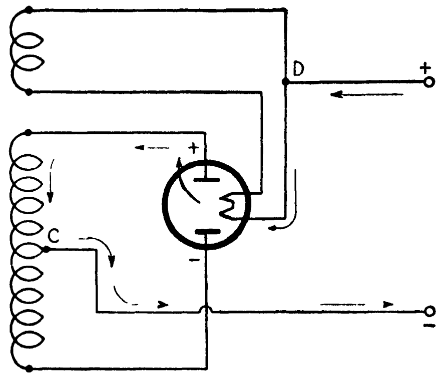


FIG. 265. Electron flow through the high-voltage secondary and the rectifier tube is shown here.

An alternating voltage of 700 volts is induced in the high-voltage secondary (see Fig. 257). The many thousands of turns of fine wire in the high-voltage secondary set up a high voltage that forces the electron surges back and forth through this winding.

How does the type-80 tube rectify the alternating current? When the secondary draws the electrons off plate 1 of the rectifier tube, plate 1 becomes highly positive. Plate 1 now attracts electrons from the space charge around the filament, and electron current flows from the filament of the rectifier tube to plate 1 (see Fig. 265).



At the next instant, the secondary voltage reverses and draws electrons off plate 2, which becomes positive. Electrons now rush from the space charge around the filament to plate 2. No electrons flow to plate 1, which now is negative.

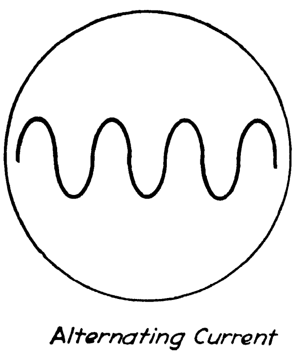


FIG. 266. This is the wave form of the direct current to each plate of the rectifier tube.

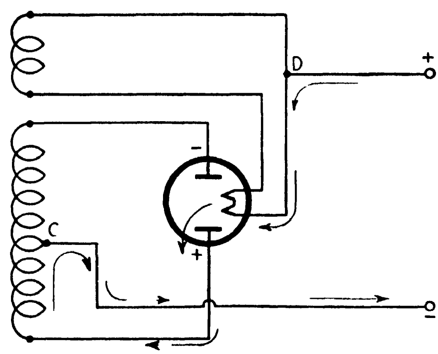


FIG. 267. The electrons flow to the set from the secondary center-tap connection. Note which connection is positive and which is negative.

The resulting electron flow, as shown in Fig. 266, is a pulsating direct current. Electrons alternately flow from the space charge around the filament to plate 2, then to plate 1, as first one plate and then the other becomes positive.

But the electrons which flow to the secondary of the power transformer from the tube must have some place to go. Electrons surge to the receiving set from the center tap of the secondary winding, as shown at *C*, Fig. 267. This is the negative connection. Elec-

trons from the receiving set come back through the wire *D* to the rectifier-tube filament. This is the positive terminal.

The pulsating direct current delivered by the rectifier tube and the secondary of the power transformer is shown in the wave picture in Fig. 268.

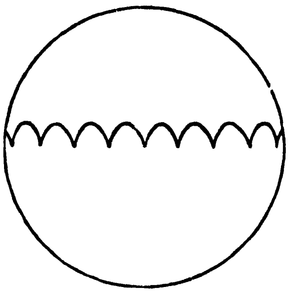


FIG. 268. The wave form of direct current from a full-wave rectifier looks like this.

The output of the rectifier tube cannot be connected directly to the receiving set, because nothing would be heard but a terrific roar caused by the rapid changes in the strength of the plate voltage.

The pulsating direct current from the rectifier tube must pass through a filter (which consists of two choke coils and three dry electrolytic condensers) before it can be used in the plate circuits of the receiving-set tubes.

The purpose of the filter is to smooth out the pulsations of the current delivered by the rectifier tube so that a steadily flowing direct current will be delivered to the set.

Questions

1. Is the type 80 a full-wave or a half-wave rectifier?

2. How are the two plates connected to the transformer?

3. Why do the electrons flow only half the time to each plate?

4. Why is the negative lead connected to the center of the secondary coil of the transformer?

5. Electrons from the receiving set return to what terminal in the rectifier tube?

6. What is the objection to connecting the rectifier tube directly to the radio?

What is the action of the filter? The standard connection for the power-supply filter is as shown in Fig. 257, with the chokes in the positive side of the circuit. This circuit will operate equally well connected as shown in Fig. 269, with the chokes in the negative lead instead of in the positive. We will show it this way for ease in explanation.

When a surge of electrons from the rectifier tube and the high-voltage secondary flows as shown by the arrow at *A*, it will meet the opposition of the choke *K*. Since the back voltage set up by the choke coil *K* opposes the surge, the electrons will flow into

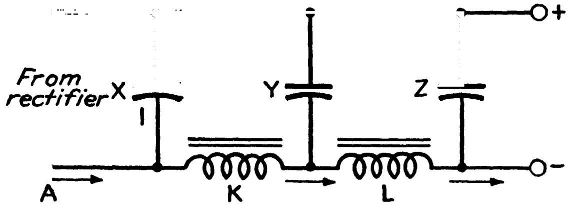


FIG. 269. The filter circuit may be arranged this way to explain filter action.

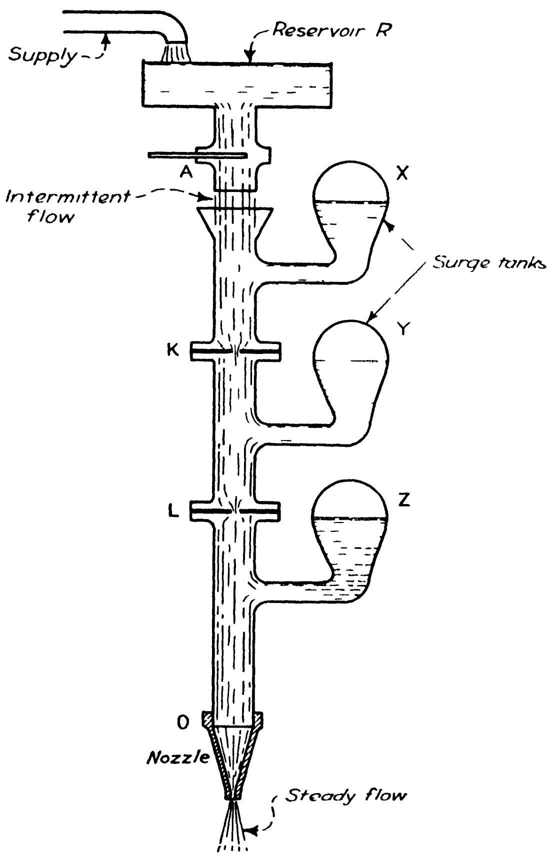


FIG. 270. Filter action may be shown by the water flow through this system.

side 1 of condenser X. As the surge overcomes the opposition of the choke coil, the current flow starts through the coil. When this surge dies down, the fly-wheel action of the choke coil tries to keep the current flowing, but there is no current remaining in this surge of electrons.

Now the electrons in side 1 of the condenser flow out and through the choke coil. The result of the action of the condenser and the coil on the first surge of electrons is to reduce the strength of the current somewhat but to deliver a more even flow. This action repeats in condenser *Y* and choke coil *L*, which even the flow further and reduce the pulsation. Any remaining pulsations are killed by the action of condenser *Z*, leaving a steady flow of direct current.

Electron Flow May Be Compared to Water Flow

Electrons surging through the filter act like a flow of water. In Fig. 270 is shown a reservoir *R* from which water flows in surges into the system of glass tubing. Two flexible dams through which there is a small opening are in the glass tube at *K* and *L*. These represent the choke coils, which hinder current surges but tend to allow the current to flow as soon as it starts. The three large bulbs at *X*, *Y*, and *Z* represent the condensers. They act as storage space.

When a surge of water from the reservoir at *R* flows into the main pipe at *A*, the dam at *K* opposes its flow. This stops the surge, and so the water, which is retarded in its flow through the system, flows into bulb *X* until it can force its way through the dam at *K*.

Questions

1. Why should the choke coils have a higher current rating than that which the power supply usually delivers?
2. Does it make any difference in which direction the current flows through an electrolytic condenser?

The Voltage Divider or Bleeder Resistor

Use the potentiometer to show the principle of the voltage divider. Connect a 50,000-ohm potentiometer, or volume control, across the 45-volt B battery (see Fig. 271). Connect a direct-current 0 to 50 voltmeter and two test points to read the drop in voltage across the ends of the potentiometer resistance element, *A* and *E*. When you set the moving contact at *B*, you will find only a fourth of the drop in voltage that you find when you set the contact at *E*. This gives the voltage drop between *A*

and E. Move the contact along the resistance to find the drop in voltage between different points on the resistor.

How can the voltage divider be used to obtain different B voltages? A voltage divider, or bleeder, is a high-wattage resistor connected across the output of the power supply. By connecting to points, or taps, along the resistor, the approximate voltage

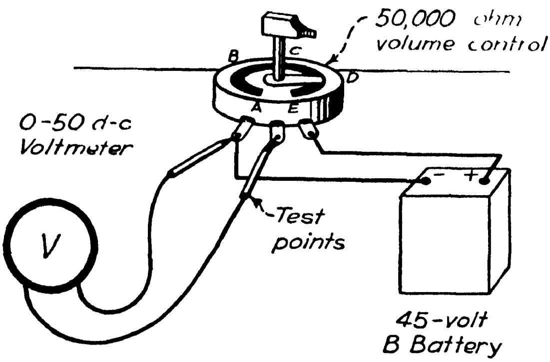


FIG. 271. A potentiometer, or volume control, can be used to show the principle of the voltage divider.

needed for each B connection can be had. Another method of getting different B voltages is to use several small resistors in series.

PART 4: HOW THE TRANSFORMERLESS POWER SUPPLY CAN BE WIRED

Small, personal radio sets have become very popular. Their low cost and small size made necessary changes in circuit design that would permit a saving in material and parts. One of the important savings was made by eliminating the transformer in the power supply. This was done by selecting tubes that could operate on a plate voltage of around 100 volts and some tubes that had high-voltage filaments. The low plate voltage eliminated the need for the high-voltage power transformer.

The filaments were connected in series. In the sets you have studied, the tube filaments were connected in parallel, as shown in Fig. 272. All the tube filaments used in a *parallel circuit* must operate at the same voltage. (All parts of a parallel circuit receive the same voltage.)

In a *series circuit*, however, each tube filament can operate on a different voltage, but the same current flows through each. Thus

you can select a rectifier tube with a 25-volt filament, five tubes with 12-volt filaments, and a power tube with a 35-volt filament, so long as all have the same current rating (see Fig. 273). The total voltage required by these tubes equals the line voltage, and so the filaments can be connected directly to the line.

$$25 + 12 + 12 + 12 + 12 + 12 + 35 = 120 \text{ volts}$$

This is near enough to 115 volts to cause no trouble.

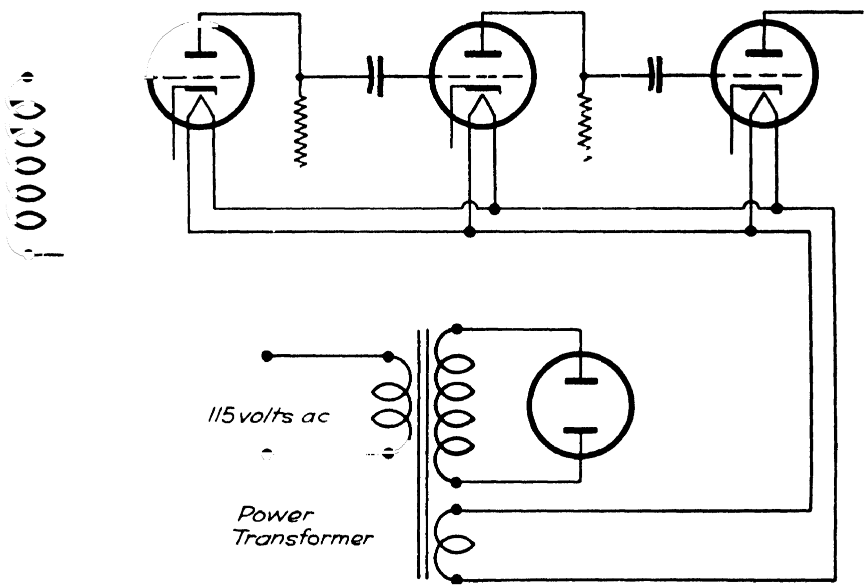


FIG. 272. The filaments in the sets you have been studying have all been connected in parallel as shown in the partial circuit shown here.

The transformerless power supply also is used in test instruments, in power supplies for photoelectric (photo-electric) cells, and in small transmitters.

What tubes are used in the rectifier and filter part of the circuit? The transformerless power supply uses a rectifier tube to change the alternating current into a pulsating direct current, a filter to smooth out the voltage variations, and resistors for voltage distribution (see Fig. 274).

What types of rectifier tubes are used? Most of the rectifier tubes used in the transformerless circuits, such as the 117Z6, the 25Z5, the 25Z3, the 35Z3, and the 35Z5, are cathode-type full-

wave rectifiers. These tubes have either glass or metal envelopes and have different types of bases. Some have the seven-prong base, some the six-prong base, and others the octal base.

Caution. Most power supplies are relatively safe to work with, because while they deliver relatively high voltages, the current through them is low enough so that an incidental shock is harmless

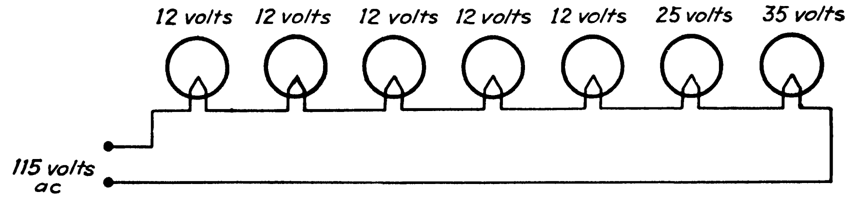


FIG. 273. But you can connect the filaments in series as shown here if the voltages required by each filament add up to the line voltage.

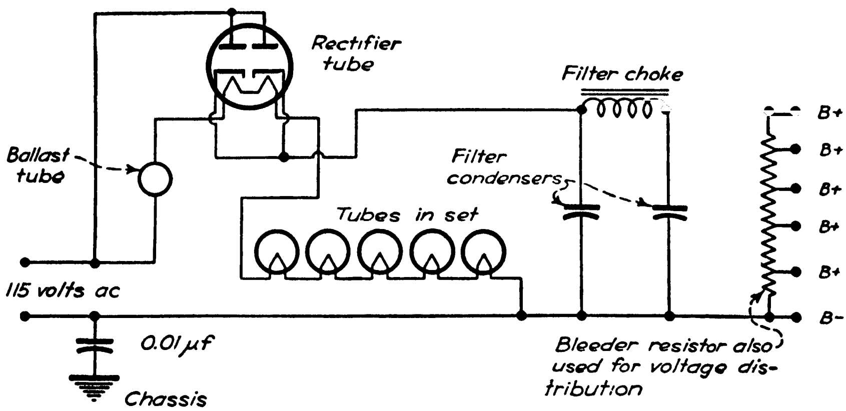


FIG. 274. The transformerless power supply rectifies the line voltage without a transformer to step up the voltage. Tubes are used in the set which require about 90 volts on the plate. The rectifier tube filament uses a high voltage.

to the average person. But in the transformerless power supply, connected directly to the line, dangerous quantities of current can flow through the circuit. Unusual care should be taken in handling a circuit with such a power supply, with the knowledge that shocks from it can be dangerous.

What capacity should the filter condensers have? The filter condensers have high capacity, of about 20 microfarads. They should be rated at about 150 volts because of the lower voltage from the power rectifier tube.

How it works. This power supply operates the same as the transformer type except that there is no voltage step-up ahead of the power rectifier tube. The line voltage is used.

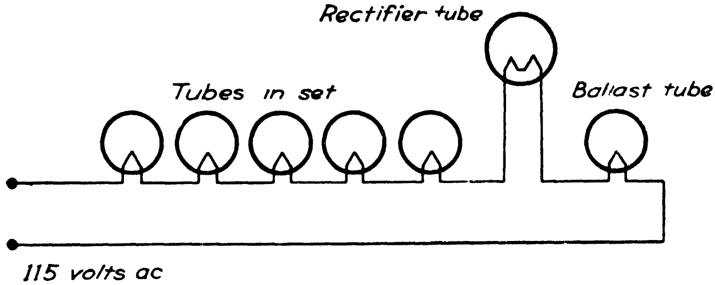


Fig. 275. The ballast tube makes up the difference in voltage between the sum of the tubes in the set and the line voltage.

Note that the filament of the rectifier tube is connected in series with the other tube filaments in the set. Note also that this string of filaments is connected directly across the 115-volt alternating-current line. When the voltage required by the tubes adds up to less than the line voltage, either a resistor is placed in series with the filaments (see Fig. 275) or a ballast tube is built into the set. The ballast tube is a resistor built inside a glass or metal tube.

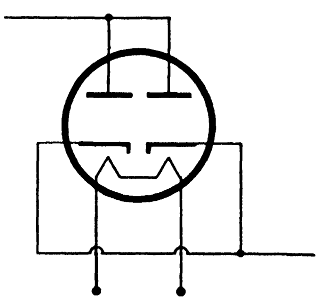


Fig. 276. The two cathodes and the two plates are connected together in parallel so that more current will flow through the rectifier tube.

How does the rectifier tube work? The two cathodes are connected together in series (see Fig. 276). The current of electrons flows from the cathodes to the plates when one cycle of the alternating current pulls in that direction. No current flows when the alternating current reverses and electrons are forced onto the plate. This is a half-wave rectifier.

How does the filter circuit operate? There are only 60 surges of electrons per second in this circuit, instead of the 120 in the full-wave rectifier you have studied. This happens because the surges flow through the tube in one direction and are stopped when they try to flow in the other.

To filter the 60-cycle current, you will need larger condensers and a larger filter choke. Less filter is needed than on larger sets, because in the small sets with few tubes the amplification is not high enough to need such complete filtering.

Practical notes. The resistance in series with the filaments may be in the line cord to keep the heat outside of the set, or it may be a ballast tube in the set, as shown in Figs. 274 or 275.

A 0.10-microfarad fixed condenser is sometimes connected from one side of the primary wire to by-pass out any radio-frequency surges picked up by the power line (see Fig. 274). Such surges may be caused by turning on or off lights, motors, etc.

In most sets the B-negative part of the circuit is connected to the chassis. Such a connection can be dangerous, because if you were to touch the metal chassis and a piece of grounded metal, such as a wall-switch plate, a radiator, or a faucet, you would get a severe shock. These sets are built so that the metal parts are covered and protected by the cabinet.

PART 5: HOW THE VIBRATOR TYPE OF POWER SUPPLY IS WIRED

If you want to take a small portable receiver or transmitter on a camping trip, you must have a group of B batteries, a small motor generator, or the vibrator type of power supply to furnish the B power for the tubes.

The vibrator type of power supply is the modern version of the old model T spark coil, which is a transformer that operates on an interrupted direct current in the primary and delivers a high alternating voltage from its secondary. The alternating current is rectified either by a power tube or a synchronous vibrator (see Fig. 277).

Examine a vibrator. Tear open a discarded vibrator. Note that it is enclosed in a heavy metal shell which is often lined with rubber or other material to deaden the buzzing sound of the vibrator reed (see Fig. 278).

The supporting frame is a piece of heavy strip metal. A small vibrator coil is mounted above the reed. The thin metal-spring reed is mounted on insulating supports. It has a piece of iron on the end near the magnet. Two arms carrying contacts are set on either side of the reed. A double contact is mounted on the reed opposite the fixed contacts. When at rest, the reed touches one

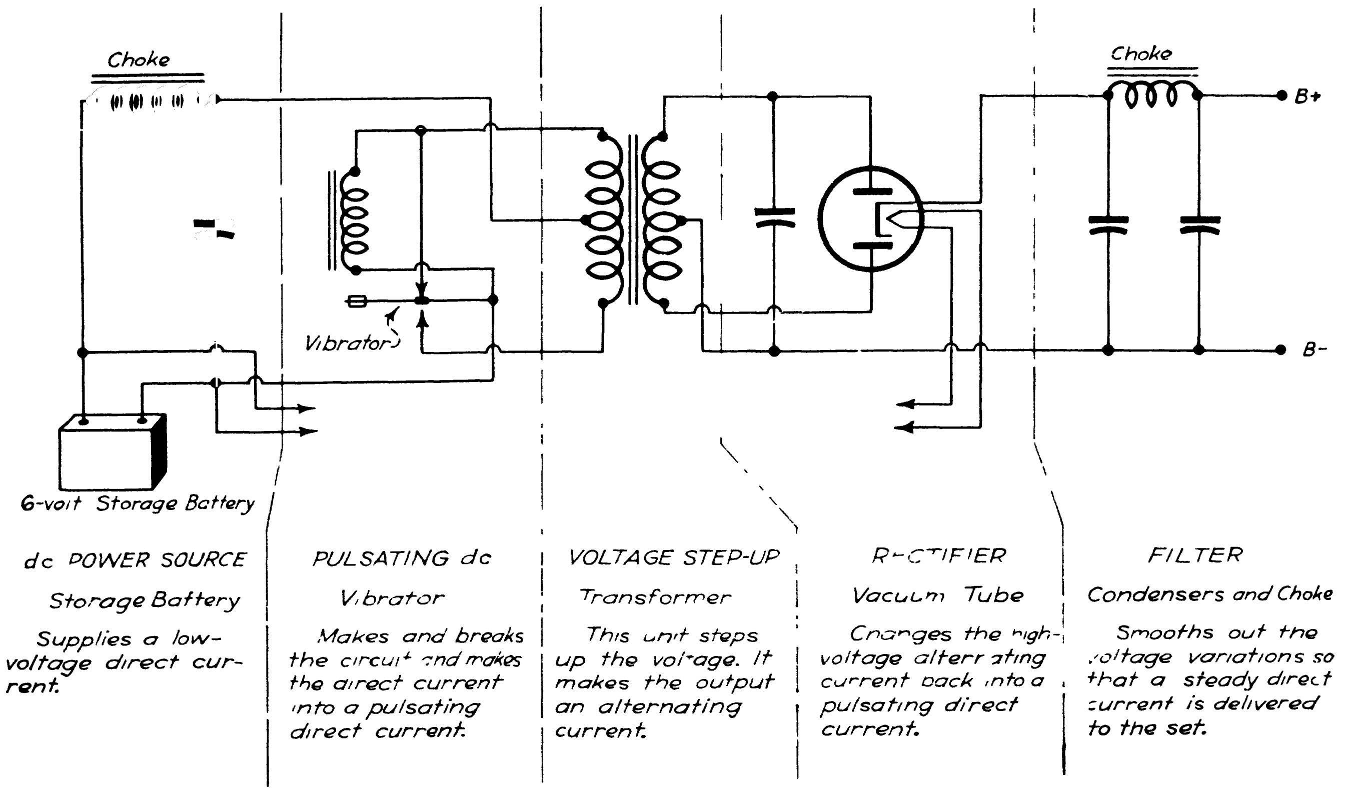


FIG. 277. Examine the parts of the vibrator-type power supply.

contact. The base is fitted with contact prongs similar to those on a tube base.

Why it works. The direct current from the battery magnetizes the vibrator coil. This pulls the iron on the vibrator reed and moves the reed away from one contact. The weight of the iron carries the reed far enough to touch the other contact.

When the contact on the reed touches the other contact, the vibrator coil is shorted out. The coil now is no longer magnetic and the reed returns to its first position, where the circuit is again made, and the cycle repeats itself.

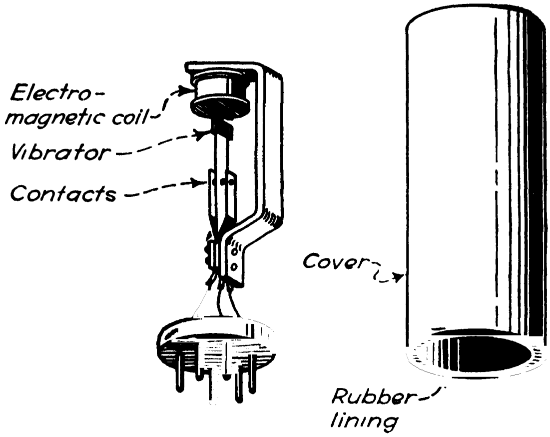


FIG. 278. The vibrator is mounted on a strap-metal frame. The coil pulls on the metal on the end of the sping reed, moves it, and makes and breaks the contacts. The cover deadens the buzzing of the reed as it operates.

Contacts make and break primary current. When the current was first turned on, it flowed through the transformer primary. The magnetic field around the primary began to grow. This induced a high voltage in the secondary.

However, when the current in the primary died out because the vibrator contacts were separated, a voltage in the reverse direction was induced in the secondary.

At this instant the other contacts touched, and a voltage was induced by the other half of the primary in the secondary. This second induced voltage helped the first.

What is the action of the rectifier tube and filter? The tube is a full-wave cathode-type rectifier, which operates in the same way as the type 6X5G described earlier in this chapter.

The operation of the filter circuit has also been explained.

Questions

1. List several characteristics of a tube which would be good for a transformerless radio set.

2. Describe a ballast tube. What is its purpose?

3. What changes must you make in the filter circuit which is designed to operate on 60 surges per second instead of 120?

4. What type of current is applied to the primary of the vibrator type of power supply? What type of current comes off the secondary?

Technical Terms

bleeder resistor—A resistor connected across the power supply to discharge the condensers in the filter and to act as a load when the power supply is temporarily disconnected from the set.

center tap—A connection made to the center of a transformer winding. Also a connection made to the center point of a resistor.

components—The parts used in a radio set, often called the *component parts*.

filter—A combination of choke coils and condensers which changes a pulsating direct current into a steady, or pure, direct current.

full-wave rectifier—A vacuum-tube rectifier which delivers a pulsating direct current from both loops of the alternating-current cycle.

metal chassis—A base made of heavy sheet metal on which the parts of the power supply are mounted.

power pack—A unit consisting of a transformer, a rectifier, and a filter which supplies both low-voltage alternating current to heat filaments and high-voltage direct current to plate circuits.

power supply—See power pack.

rectifier—A vacuum tube which changes an alternating current into a pulsating direct current.

ency of the filament to heat and cool too rapidly by using a filament wire that was very much heavier than the light filament wire used in the early direct-current tubes.

The heavy filament in the early alternating-current tubes was a ribbon about as wide as the spade end of a toothpick (see Fig. 280). These early tubes used an alternating current successfully on the filament only because the filament was so heavy. This filament is heavy enough to remain at the same temperature during the time the alternating current is reversing. It has a high *thermal inertia*, or heat laziness; that is, it is not sensitive to quick heat changes. The electron surges of the 60-cycle alternating current are too rapid to affect the temperature of the heavy filament.

Questions

1. What is the effect of putting an alternating current on the filament of a direct-current tube?
2. Why is it that a direct-current tube does not emit a steady stream of electrons when the filament is heated by an alternating current?
3. What was the first successful method used to get a filament to emit a steady stream of electrons when it was heated by an alternating current?

PART 2: HOW THE HEATER-CATHODE TYPE OF TUBE IS CONSTRUCTED

A detector tube must be entirely hum-free. The filament type of tube still left some hum in the signals, and so another kind of electron source was needed that would deliver a perfectly steady stream of electrons. This problem was solved by separating the two jobs of the filament. The filament no longer was used both as a stove, or heater, and as an electron emitter. Its task now was to heat the cathode, which took over the job as electron emitter. The filament, inside the metal cathode, could cause little or no hum.

The first alternating-current tube you will use is the 6C5. You can use it either in the detector or in the audio-amplifier circuit.

How the 6C5 tube is used. The 6C5 is a general-purpose, three-element tube used in alternating-current sets in place of the 1LE3 direct-current tube discussed in an earlier chapter.

The characteristics of the 6C5 and the 1LE3 tubes are roughly the same. The 6C5 may be used in the 1LE3 circuits with no changes in B voltage. The difference in the 6C5 circuit is that the B minus and the grid-return wire must be connected to the cathode and the alternating-current filament-heater current is sup-

plied by a filament transformer. The 6C5 tube has an octal base and must be supplied with a 6.3-volt alternating current for the heater.

How it works. The filament in this tube is a tiny stove which heats the cathode.

The cathode is a small metal sleeve coated with alkaline-earth oxides, rich in materials that give off electrons when heated (see Fig. 281). The cathode fits over the heater filament. There are several methods of fitting the filament in the cathode. In some

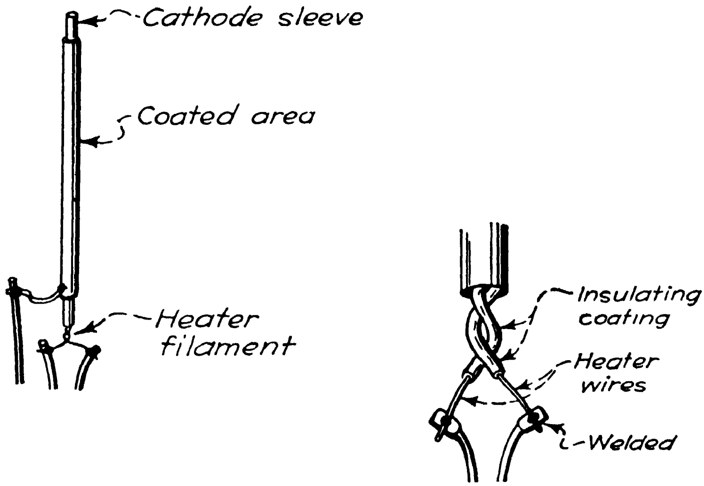


FIG. 281. The cathode is a long metal tube coated with earth oxides. The heater filament, coated with insulation, is twisted and inserted inside the cathode.

tubes the heater filament is run through tiny holes in a ceramic, or porcelain-like, substance; in others the filament is twisted and suspended tightly in place.

The hairpin filament must be insulated from the metal cathode sleeve. The metal sleeve shields the other tube elements from the alternating-current magnetic field around the filament wires. This prevents hum in the tube.

How the alternating-current hum is killed. When the current is turned on, the filament heats quickly and acts as a stove, or heater, for the cathode, which is so much heavier than the filament that it heats slowly. The temperature changes of the filament occur as rapidly as the surges of the alternating current change, but they do not affect the temperature of the cathode.

It is too heavy and large to heat up or cool off that fast. Its thermal inertia is very high.

The hot cathode gives off a stream of electrons at a sufficiently steady rate so that the 6C5 tube can be used as a detector as well as an amplifier. The hum has been cut out by substituting the cathode for the filament as the source of electrons. You can watch the filament and cathode of the 6C5 heat up when the current is first turned on. You can see the effect of the high thermal inertia of the cathode. Notice how slowly the cathode heats to operating temperature. Compare the time of heating in a 1LE3 and a 6C5 tube.

A transformer supplies filament current. A step-down winding on the transformer in the power supply delivers the low-voltage alternating current which is used by the heaters, or filaments, of the different tubes in the circuit.

Questions

1. What is the cathode like in a 6C5 tube?
2. What is the purpose of the cathode?
3. Explain why it is that the cathode remains at an even temperature.

PART 3: WHAT TUBE BASES AND TUBE SOCKETS ARE USED

Early tubes had no bases. Tube sockets and bases from the very first have been a problem. A tube base and socket must be designed so that the tube can be plugged into a socket only in the right way. If the tube were plugged in incorrectly, it might burn out the tube filament. Many an early experimenter connected up his tube, attached the batteries, and watched $7.50 disappear in a flash because he had incorrectly connected the B battery to the tube filament. The early De Forest Audion tube had no socket. Wires from the tube elements were sealed into the glass envelope. These wires were connected into the circuit.

Soon glass tubes were cemented into a base. Wires from the tube elements were brought out to base pins, or prongs. A pin on the side of the insulating base fitted into a slot in the socket. This was the bayonet type of base and socket.

How are tube bases and sockets made foolproof? Even on the early WD11 series of tubes, you find one of the prongs larger, so that it would be impossible to plug this tube into the socket incorrectly.

The early socket was an insulating base fitted with spring con-

tacts and a metal shell into which the tube base was slipped. The tube prongs made contact with these springs. Another socket. the flat-wafer type, is widely used at present. In it, spring contacts are attached to a Bakelite base. Most modern sockets have a wiping contact between the spring and the tube-base pins. The wiping contact cleans itself when the tube is inserted in the socket.

For ultrahigh frequency circuits, porcelain bases and sockets are a necessity, because many of the common plastics are poor insulators at the high frequencies.

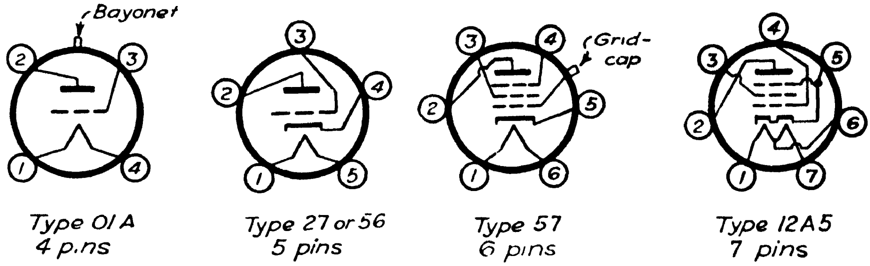


FIG. 282. These different tube symbols show the numbering system for the base prongs of a variety of tube types.

The multielement tubes required more pins. When the tubes that are used in alternating-current circuits in other words, the heater-cathode type of tubes and the screen-grid and pentode tube were developed, more pins were needed on the tube bases. This brought forth the five-, six-, and seven-pin tube bases. Manufacturers systematized the way in which elements were connected to tube pins, so that constructors and repairmen could work easily with socket connections.

How are tube-base pins numbered? Tube diagrams are drawn showing the socket connections *when viewed from the bottom*. This is convenient, because set constructors and servicemen work with the set turned upside down so that they can work on the wiring which is located under the set chassis. Figure 282 shows the connections to the once-popular triode detector-amplifier tube, the 01A. Note that the numbering starts with one of the filament pins and runs clockwise around the socket as seen from below. This system is still used.

Four-pin tubes have two large pins connected to the filament (see Fig. 282). A five-pin tube has pins all the same size but spaced irregularly so that the tube can be plugged into the socket in only one way. The pin numbers are shown in Fig. 282. Note

the difference between the five-pin octal socket for the 6C5 and the six-pin octal socket for the 35Z5. See the Radio-tube Characteristics Charts, pages 668–693.

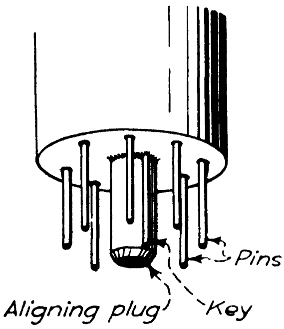


FIG. 283. The octal tube base. Note the eight base pins, the aligning plug, and the key that allows the tube to be inserted into the socket only in the correct position. The pins are all the same size.

A six-pin tube has two large pins for the filament. The large filament-heater pin helps you find the position of the base when you plug in the tube (see Fig. 282 for pin numbers).

The seven-pin-tube base also has two large pins (see again Fig. 282 for pin numbers).

How is the octal socket made? Many modern tubes commonly use the octal-type of base and socket (see Fig. 283). Octal tubes are designed with positions for eight pins. (*Octal* means eight.) In some tubes all eight pins are cast into the socket; in others some of the pins are omitted, but when this is done, the remaining pins are placed in position to fit

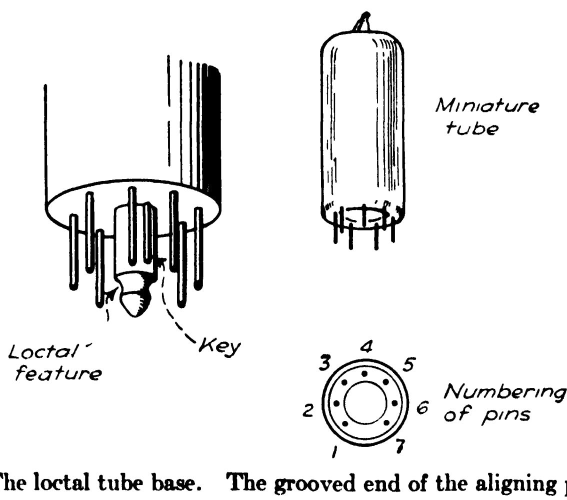


FIG. 284. The loctal tube base. The grooved end of the aligning plug prevents the tube from being worked out of the socket by vibration. Note the key on the side of the plug. The minature tube has the wire pins cast in place in the glass base.

into the standard octal socket. The key, a raised projection that is cast onto the aligning plug (see Fig. 283), fits into a slot in the socket so that the tube can be inserted in only one position.

How is the loctal socket made? The loctal-tube base has a groove around the end of the aligning plug. A spring in the socket grips this groove so that the tube cannot be loosened by vibration (see Fig. 284).

How is the tube base formed in miniature tubes? Miniature tubes have wires cast into the glass to form a tube base (see Fig. 284). This construction eliminates the long wires connecting the elements to the pins inside the tube base. In the high-frequency circuits especially, the capacity between these wires and the metal pins is great enough to affect the operation of the circuit.

How is tip connection for the grid made? In some tubes connection to the grid is made to a grid cap on the top of the tube. This construction keeps the highly sensitive grid-connection wire away from the other leads to the base pins. Note the metal grid-wire shield in the tube.

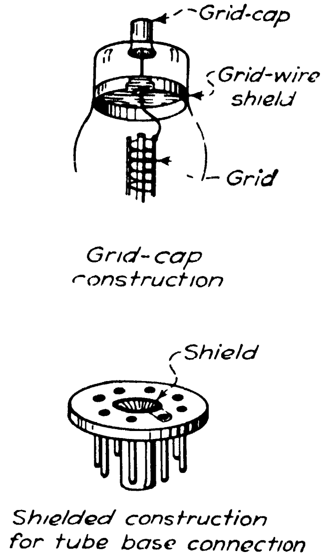


FIG. 285. Types of control grid connections. Top connection: a metal shield in the dome of the tube protects the grid wire from stray fields and from the other tube elements. Base connection: here the shield is inside of the aligning plug. It is connected to the grounding pin on the tube base.

Later design eliminated the grid cap. Designers found a way to bring a wire from the grid down into the tube base without causing trouble at moderately high frequencies inside the tube. A shield protects the wire from stray fields and from the other element leads (see Fig. 285).

Questions

1. Examine a commercial home radio set to find the plate currents and filament voltages of its tubes. Look up this information in a tube manual.

2. Make a list of the different ways in which tubes are designed so that they cannot be plugged in incorrectly.

PART 4: HOW TO UNDERSTAND TUBE CHARACTERISTICS

Before you can understand why a tube is best fitted for some particular job in a radio circuit, you must know something about its characteristics, such as its ability to amplify, its plate resistance (which affects the amount of plate current that flows), the amount of its plate current, and its grid-bias voltage for different circuits. You also will need to know the filament voltage and current for the tube. There are other engineering characteristics, but you will leave them for later study in a more advanced text.

Engineers need terms to describe the operation of a radio tube. You will study terms expressing the effectiveness of the tube as an amplifier, describing the resistance of the vacuum to a flow of electrons through it, and describing accurately the tube's action when definite voltages are applied to its different elements. Each term has a definite meaning and represents a definite quantity, or number, so that a radio engineer designing a set using this tube can plan his circuit to do specific things.

This information is given in the Radio-tube Characteristics Charts, pages 668–693.

You will now learn the meaning of three of these terms—*plate resistance*, *amplification factor*, and *mutual conductance*—so that you can use them with a degree of understanding in your further study of tubes and circuits. They will be explained in a simple manner.

What is plate resistance? The *plate resistance* of a tube represents the opposition to the flow of alternating-current electron surges from the filament, or cathode, to the plate, measured when the grid is neutral. Plate resistance is also called *plate impedance*, because it is measured with an alternating current instead of a direct current. When the tube is operating with an alternating-current voltage on the grid, the number of electrons flowing to the plate changes, and this changes the internal, or plate, resistance of the tube. The plate resistance depends on the size of the tube elements, the distance between them, and the voltage between the filament and plate.

Tubes with Low Plate Resistance. The tube with low plate resistance has a large cathode, or filament, that can supply many electrons and has the plate relatively close to the cathode (see

Fig. 286). The type-2A3 tube has very low plate resistance. It carries from 40 to 60 milliamperes of plate current, and when used as an amplifier, it can deliver more than 3 watts of power to a loudspeaker. Other tubes with high plate current and low plate resistance are the 31, 45, 6A3, 6B4, and 71A. These tubes are used in power-audio-amplifier circuits.

Tubes with High Plate Resistance. In a tube with high plate resistance, relatively few electrons are able to reach the plate from the cathode; there is a small supply of electrons, and the plate is

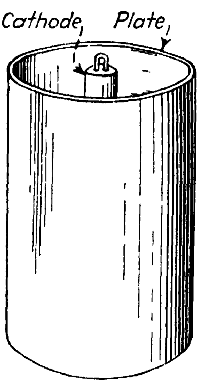


FIG. 286. A tube with low plate resistance has the plate close to the cathode.

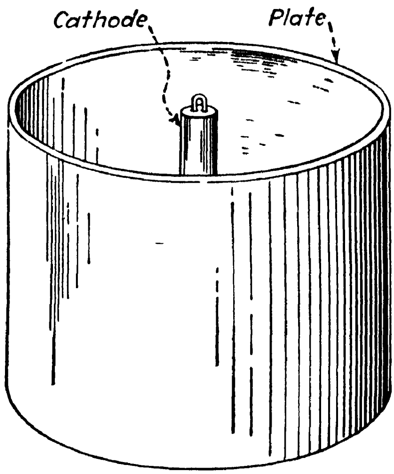


FIG. 287. A tube with high plate resistance has the plate far from the cathode.

at a greater distance from the cathode, or filament (see Fig. 287). Tubes with high plate resistance and low plate current include the 1B4, 1N5, 6AC5, 6C6, 36, 58, and the 77.

What is the amplification factor of a tube? A small voltage change on the grid increases or decreases the plate current as much as a large change in plate voltage would change the plate current. An example will make this clear. If you make the grid of the 6C5 triode 1 volt more positive, this will increase the plate current as much as if you were to increase the plate voltage by 20 volts. This effect is known as *amplification.* The ability of the tube to amplify is called the *amplification factor* of a tube (represented by the Greek letter mu). The amplification factor, or mu, of this tube is 20.

High-mu Tubes. A high-mu tube is one which has a very high amplification factor. An example of this is the 6AC5 tube, which has an amplification factor of about 125, depending on the plate voltage. The 6AC5 tube is so sensitive that a change of 125 volts is required on the plate to equal the effect that a change of 1 volt in the grid circuit will produce on the plate current. This type of tube is very sensitive when used as a detector or as a radio-frequency amplifier, since it is able to operate well when the grid is driven, or excited, by a very low voltage.

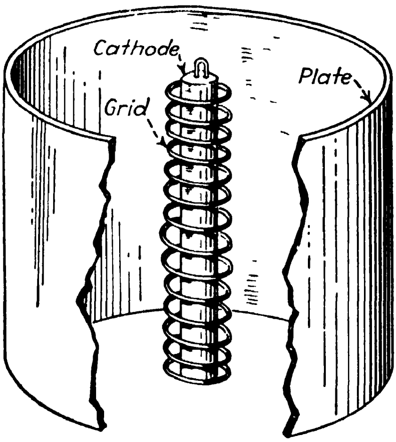


FIG. 288. The grid wires are closely spaced in a high-mu tube.

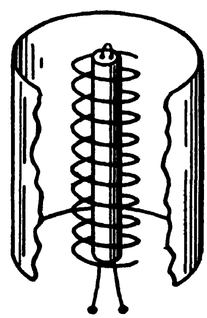


FIG. 289. The grid wires are farther apart and are also farther from the grid in a low-mu tube.

The high amplification factor of this tube is obtained by placing the grid wires very close to the cathode, with the grid wires spaced close together (see Fig. 288).

Low-mu Tubes. A low-mu tube is one which produces a comparatively small voltage increase but which will handle much current. The type-45 tube with a mu of 3.5 operates so that a 1-volt change on the grid produces the same change in plate current as will a 3.5-volt change on the plate. The grid wires are farther from the filament, or cathode, and are spaced farther apart (see Fig. 289). This is possible because more current flows through the tube. Low-mu tubes are generally used as power amplifiers. The type 45 handles about 30 milliamperes of plate current with an amplification factor of 3.5.

Questions

1. What is plate resistance?
2. How is the type-2A3 tube made so that it will have a low plate resistance?
3. What types of circuits use tubes with low plate resistance?
4. Does the 6AC7 tube have low or high plate resistance?
5. Explain what is meant by the amplification factor of a tube.
6. How is a tube constructed so that it will have a high amplification factor?

What is mutual conductance, or G_m? The term G_m, or *mutual conductance*, describes the amplifying ability of a tube better than the amplification factor does, because it makes allowance for both the plate resistance and the amplification factor.

Mathematically it is shown this way:

$$\text{Mutual conductance} = \frac{\text{amplification factor}}{\text{plate resistance}}$$

Simplified, G_m represents the effect that a change of 1 volt on the grid will have on the plate current *when the plate voltage is held the same.*

The G_m of a tube is expressed in micromhos. The *micromho* is 1 millionth of a *mho*, which is pronounced mō. The term *mho* is *ohm* spelled backward. It is used because *ohm* represents *resistance* to current flow, whereas *mho* represents *conductance*, or the ease with which current flows.

How to Draw a Grid-voltage—Plate-current Curve

When you set up the grid test with a neon tube (Chapter 7, "Principles of the Vacuum Tube") you saw that making the grid more positive made the plate current stronger and that making the grid more negative made the plate current weaker. You also saw that the grid could be made negative enough to cut off the plate current completely, so that the neon tube ceased to glow. You *saw* these effects then, but to use the vacuum tube in detector and amplifier circuits, you should *know* just how these effects occur. You must know how much 1 volt on the grid will cause the plate current to change.

In this experiment you will use a meter to measure the current values in the plate circuit as you change the grid voltage, and then you will draw a curve that shows how these changes occur. Such a curve has many uses for an engineer who is designing circuits.

From it he can find the best voltages and current values to use on a detector or amplifier tube for different operating conditions.

How to Build and Wire the Circuit Board

The circuit board is the same as the one used for the 1LE3 tube, described in Chapter 7. An octal socket is required for the 6C5 tube.

Note the changes in connections for the octal socket (see Fig. 290). The cathode wire is connected to terminal 8 on the octal socket. Note that several terminals on this socket are unused.

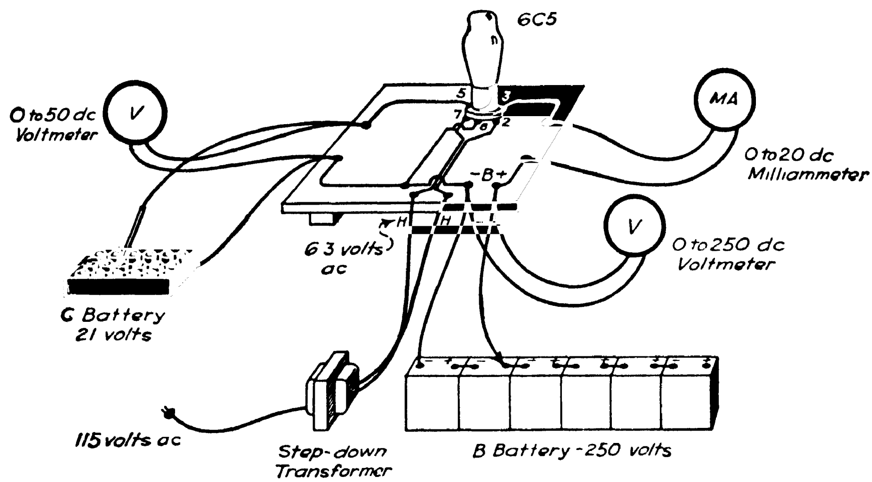


FIG. 290. The hookup for taking the grid curve.

How to Operate It

You will need a 0 to 50 direct-current high-resistance voltmeter for reading the grid voltage, a direct-current 0 to 250 voltmeter for B-voltage readings (see Figs. 290 and 291), and two direct-current plate-current meters of 0 to 10 and 0 to 20 milliammeters.

Connect the 0 to 50 voltmeter to read the grid voltage, as in Figs. 290 and 291. See that the positive side of the meter is connected to the board terminal to which the positive terminal of the C battery is connected, or the meter will read backward.

Hook up the plate circuit. Connect a 0 to 250 direct-current voltmeter to the B-positive and B-negative binding posts to check the plate voltage. Connect a 0 to 20 direct-current milliammeter to the output posts on the set board.

Caution. First try a 0 to 20 direct-current milliammeter to find the amount of current that will flow, and then replace it with a meter of lower range for your test.

Connect the C, or grid-bias, battery. Connect enough dry or flashlight cells in series to make a 21-volt C battery.

Place this battery near the circuit board so that the test point from the grid post can be handled easily when you run the test.

Hook up the grid circuit. Attach the wire from a test point to the input post that leads to the tube socket (pin 5). Connect a wire from the input post connected to the cathode, pin 8, to the

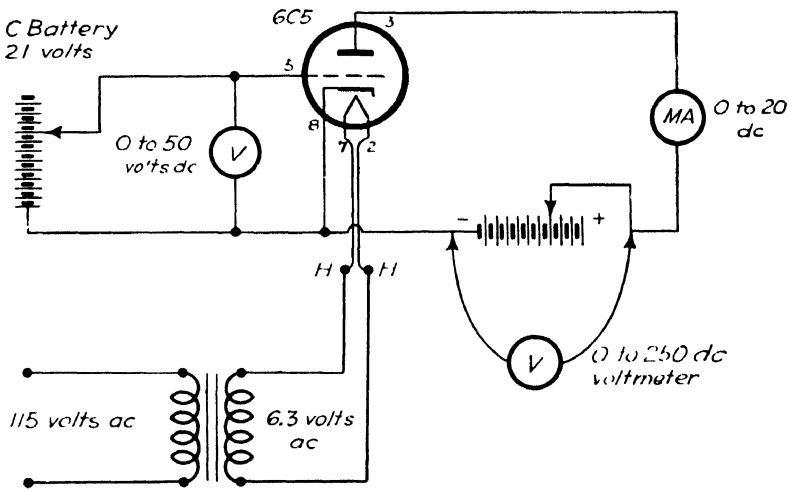


FIG. 291. The schematic diagram of the circuit used for making the grid curve.

negative end of the C, or bias, battery. It will be necessary to connect this wire to the grid for the zero reading.

Check the meters. Be sure the polarity of the connections of each meter is right so that the meter hand does not swing backward.

Connect the heater and B battery. Connect the 6.3-volt alternating-current leads from a step-down transformer or a power supply to the heater terminals on the set board.

Run the first test as directed in the next paragraph, with a 22.5-volt B supply. Then run other tests with 45 volts and on up to 250 volts.

Touch the wire from the B battery to the B binding posts. Check the reading of the plate milliammeter to see that the hand moves in the correct direction. If it is correct, fasten the wire to

the binding post. Reverse the wires to the meter if the hand moves in the wrong direction. Check the B voltage with the 0 to 250 direct-current voltmeter. The test leads from this meter are connected across the B-minus and B-plus terminals on the board as explained earlier.

		PLATE CURRENT in milliamperes for various plate voltages			
		VOLTAGE ON THE PLATE			
	GRID VOLTS	25	50	100	150
Negative ← O → Positive	10.5	20.5	27.0	36.0	45.0
	9.0	17.5	23.0	32.5	40.0
	7.5	15,0	19.5	28.0	35.5
	6.0	12.0	16.0	24.0	31.0
	4.5	9.0	12.5	20.0	27.5
	3.0	6.5	9.5	16.0	22.5
	1.5	4.0	6.0	12.5	18.0
	0.0	1.0	4 0	7.5	14.0
	1.5	0.32	1.50	5.50	12 OC
	3.0	0.10	0.25	2.50	7.00
	4.5	—	0.20	1.00	4.00
	6.0	—	—	0 50	2.00
	7.5	—	—	—	1.00
	9.0	—	—	—	0.70
	10.5	—	—	—	0.60

FIG. 292. Data sheet. These different values of plate current were obtained from a test run with a 6C5 tube.

How to Run the Test

Step 1. Take readings with grid positive, or positive bias. Touch the test point to the positive post of the first C-battery cell. There should now be 1.5 volts on the grid.

Read on the milliammeter the value of the current flowing in the plate circuit. Make a record sheet similar to the one shown in Fig. 292. Write this reading on the record sheet opposite 1.5 grid voltage. See Fig. 293 for sample curves of a test in which the grid bias was increased in steps of 1.5 volts.

Now move the test point to the next C-battery cell. Touch the positive post. There are now 3 volts on the grid.

Write the reading of the milliammeter opposite 3 volts in the plate-milliamperes column on the record sheet.

Take a reading for each cell added to the C battery as the test point is touched to its positive terminal.

What effect does increasing the positive voltage on the grid have on the plate current?

Step 2. Take readings with grid negative, or negative bias. Connect the wire from the cathode post on the tube socket to the positive terminal of the C battery.

Touch the test point to the negative terminal of the first cell from the positive end of the C battery. Write the plate-current reading in the negative section on the record sheet.

Take readings, one cell at a time, until a C voltage is reached at which no current flows in the plate circuit. This is the *cutoff point.*

Does the plate current decrease an equal amount for every volt of negative bias added to the grid?

Step 3. Take the zero reading. Touch the test point connected to the grid to the wire or terminal connected to the cathode and the B-minus terminal of the B battery. Read the milliammeter to get the zero grid-voltage reading. If either wire is connected to the C battery, or if your hands are touching either wire, the reading will be inaccurate.

Step 4. Draw the curve. Draw the base line for the grid voltages at the bottom of the graph paper (see Fig. 293). Draw the zero grid-voltage line as shown. Draw the plate current base line at the left of the graph paper. Locate the points and complete the curve. Repeat for several different plate voltages, such as 22.5 volts, 45 volts, 90 volts, 180 volts, and 250 volts.

Draw a separate curve for each plate voltage.

Why It Works

You allow only one voltage to change. During each test you kept the same plate voltage for the test. This meant that the pulling power of the plate did not change.

The only voltage you allowed to change was the voltage on the grid. This you changed in uniform steps, adding 1.5 volts between each reading.

In this way you were able to watch the effect on the plate current flowing through the tube as each change of grid voltage occurred. You then knew that the changed grid voltage was the only thing which affected the plate current.

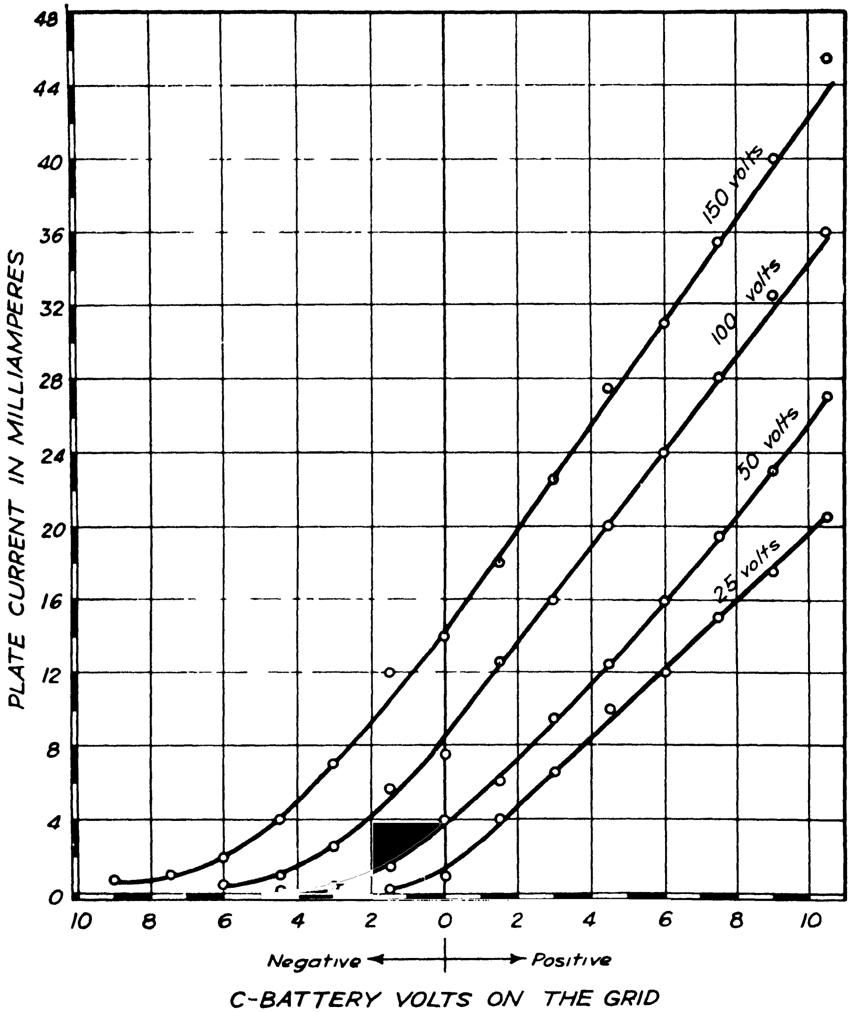


FIG. 293. Sample curves showing grid control of plate current for the 6C5 tube.

Any changes of plate or filament voltage during the test would have been very confusing, because you could not know definitely that the change in plate current was caused only by the change in grid voltage.

How does a positive grid affect the electron flow? In most receiving sets, the grid is kept slightly negative, but it is interesting to know what effect making the grid positive will have on the electrons flowing from the filament to the plate.

When you say that the grid is positive, you mean that electrons on the grid have been pumped away by the C battery. The grid has few free electrons. But the grid is placed between the filament and the plate in the path of the streams of electrons.

The positive grid then will attract electrons from the filament and will add its pull to that of the plate. The pull of the grid is weak, since the C voltage is small, but it is enough to attract electrons. This adds to the speed of electrons in the space charge, so that more fly toward the plate.

The fine wires of which the grid is made allow many of the electrons it attracts to fly onward and reach the plate. You know this is so because the reading of the plate milliammeter shows more current in the plate circuit as the pull of the grid is made stronger by the positive C battery.

The curve in Fig. 293 shows that 8 milliamperes of current flowed through the tube with zero voltage on the grid (see the curve with 100 volts on the plate). But when you make the grid 5 volts positive, the plate current increases to 21 milliamperes. As you make the grid more positive, the plate current becomes stronger.

This part of the curve is nearly straight. A straight-line graph shows that each volt added to the grid increases the plate current by the same amount. A tube with a straight-line curve is a good amplifier. If the line is not straight, signals will be distorted.

How does a negative grid affect the electron flow? When you change the connection of the grid circuit so that the negative side of the C battery is connected to the grid, electrons are pumped on the grid from the C battery.

Electrons are negative charges of electricity. The electrons on the grid now repel the electrons from the cathode. Not as many electrons can reach the plate because of the repelling action of the electrons on the grid.

The curve shows that as the grid becomes 5 volts negative, only $\frac{3}{4}$ milliampere of current is flowing.

What is the cutoff point? You find that when enough electrons are forced onto the grid by the C battery, no more electrons from

the filament are able to pass through the grid. The pushing-back action of the electrons on the grid stops them entirely. This is the *cutoff point.* The grid is negative enough to stop the plate-current flow. On this grid, 8 volts stopped the current flow with 90 volts on the plate.

Questions

1. Why do most of the electrons fly on past the grid?
2. What effect will making the grid negative have upon the flow of electrons to the plate?
3. What is meant by the term *grid cutoff point?*
4. Define mutual conductance, G_m.

What is the effect of higher plate voltage? When you connect a B battery to the plate circuit so that the voltage is raised, you find at once that the amount of current flowing through the plate milliammeter has increased. The higher voltage on the plate makes a stronger pull on the electrons. More electrons are swept away from the whirling cloud of the space charge and from the cathode.

You also find that more negative bias is needed to overcome the stronger plate pull and stop the electron flow. More negative voltage is required to cut off the flow.

PART 5: HOW THE SCREEN-GRID TUBE IS MADE

When the triode tube was used in the circuits of early radio-frequency amplifiers, the set squealed and howled badly. Professor Alan Hazeltine of Stevens Institute of Technology developed the famous neutrodyne circuit to stop this howl. He found that the howl was caused by feedback from the plate circuit of the amplifier, through the tube, into its grid circuit. The feedback, he found, was caused by the capacity (or condenser effect) between the grid and the plate inside the tube. Although this capacity was very small—only 8 micromicrofarads in the tubes then used—it was enough to feed surges back through the tube that interfered with those in the grid circuit and produced an unpleasant howl.

Professor Hazeltine solved this problem by connecting a very small variable condenser from the grid circuit to the plate circuit, so that surges could be fed to the grid *around* the tube that would oppose and kill the surges fed *through* the tube. This was the

neutrodyne circuit (see Fig. 294). Though it is seldom used in modern receivers, you will find it in some form in many mod-

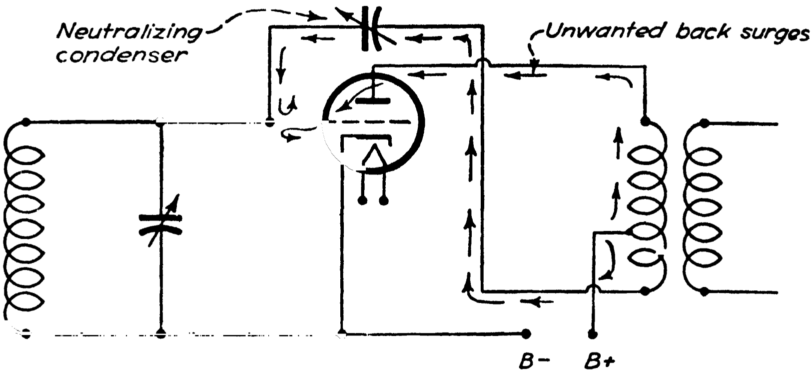


FIG. 294. In the older neutrodyne receiver, the unwanted surges were killed or neutralized by surges fed back to the grid circuit through the small variable condenser. This is a radio-frequency amplifier circuit. It will be explained in a later chapter.

ern transmitters. The action of the neutrodyne circuit will be explained in detail in Chapter 20, "Power Oscillators and Amplifier Circuits."

How does the screen-grid tube prevent feedback? Later, feedback was prevented more simply by a new tube construction. A second grid was placed between the plate and the grid (now called the *control grid*), and this shielded the unwanted plate surges from the control grid. The new element was called the *screen grid* (see Fig. 295). In the screen-grid tube, surges on the plate drive electrons on and off the screen grid but do not affect the control grid.

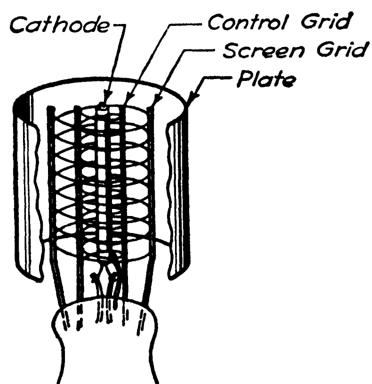


FIG. 295. Elements of the screen-grid tube. The added part is the new screen grid. In some tubes the screen is also built outside of the plate.

Note in Fig. 296 that the screen grid is connected to the B battery, or power supply, so that the surges forced on the screen have no effect on the grid circuit and the tendency to howl is eliminated.

In this tube the interelectrode (inter-electrode) capacity between the plate and the control grid is reduced to 0.01 micromicrofarad or less.

What are some screen-grid tubes? The 1D5, 24A, 32, 35, and 36 are typical screen-grid tubes.

The 24A is the older 2.5-volt alternating-current heater type of tube. It has a five-pin tube base. Its connections and terminal numbers are shown in a tube manual.

The pentode tube is now used in place of the screen-grid tube. Its added grid gives it many advantages over the older tube.

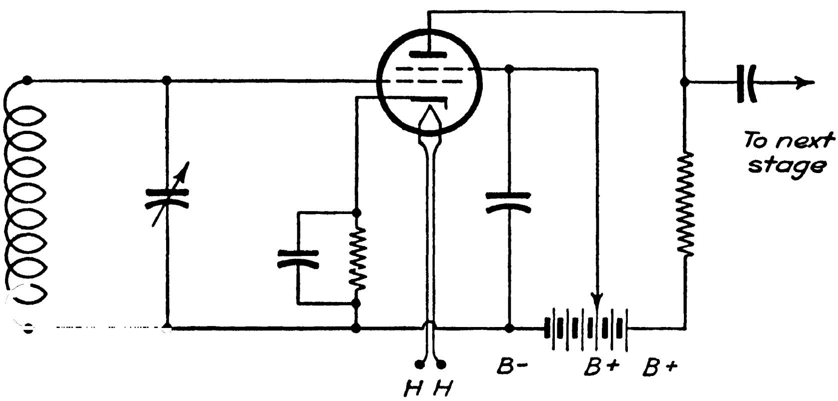


FIG. 296. The circuit of the screen-grid tube. Note the screen connection to the B plus is at a place where the screen is about half the voltage of the plate.

What are remote-cutoff tubes? The 6AU4 is a *supercontrol*, or *remote cutoff*, pentode-type tube. Ordinary screen-grid tubes are such excellent amplifiers that they bring in local signals too strongly, and they block the set. This means that the grids become so negative that the set stops playing for a time. Remote-cutoff screen-grid tubes overcome this difficulty.

The control-grid wires in a remote-cutoff tube are wound close together at the upper and lower ends and are spaced farther apart near the center (see Fig. 297). The closely spaced ends allow electrons on the grid from a weak station to have good enough control of the electron stream for the set to play well. But when strong signals from a powerful station reach the grid, the wires are spaced far enough apart so that electrons can still get through and the set will continue to play.

How is the screen-grid tube used? The screen-grid tube made DX listening possible for the broadcast listener. Distance, abbreviated by amateurs as DX, requires a sensitive receiver. While the older 01A tubes could be used for DX circuits, reception was critical and the set was hard to tune. Feedback inside the tube made the circuit howl.

However, the screen-grid tube could be made so sensitive that DX was much easier to pick up on a broadcast set.

The screen-grid tube is both a good amplifier and a good detector because of its high amplification factor and G_m. However, its plate resistance is high and its plate current small, so it is a poor power-amplifier tube.

The closely spaced grid wires, mounted near the cathode, give excellent control of the electrons flowing to the plate. The amplification factor, or mu, is around 400. This is quite high when compared with the mu of the triodes, such as the 1LE3, which is about 14.5, or with the 6C5, which is 20. Remote-cutoff pentodes are now used in place of the screen-grid tube.

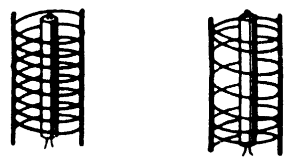


FIG. 297. The wires of a regular control grid are evenly spaced while the wires of the supercontrol grid are closer at the top and bottom of the winding.

Close spacing at the ends of the supercontrol grid gives the tube good control of the plate current for weak signals. The wide spacing at the center of the grid allows electrons to get through when loud signals are being received.

PART 6: HOW THE PENTODE TUBE IS MADE

The five-element, or pentode-type, tube retains the high sensitivity of the screen-grid tube, and, in addition, a new element, the *suppressor grid*, increases its efficiency. The pentode has a higher G_m than have the triode or screen-grid tubes. When it is used in an audio amplifier, one less audio-amplifier stage is required, and the detector can be coupled directly to a pentode power tube to operate a loudspeaker. Also, because the amplification in each stage is high, the pentode may be used as a radio-frequency amplifier. A one-stage amplifier using a pentode has an output equal to several amplifier stages using triodes.

What are the characteristics of the pentode? The pentode tube, used for a voltage amplifier, has low plate current and high amplification. It is a good amplifier, because small grid-voltage changes cause large changes in the plate current.

Its plate current is from 1.2 to 3.5 milliamperes with 250 volts on the plate.

Typical pentodes used for radio-frequency voltage amplifiers or detectors are the 6AC7, the 6J7, the 6SK7, and 7B7. Good

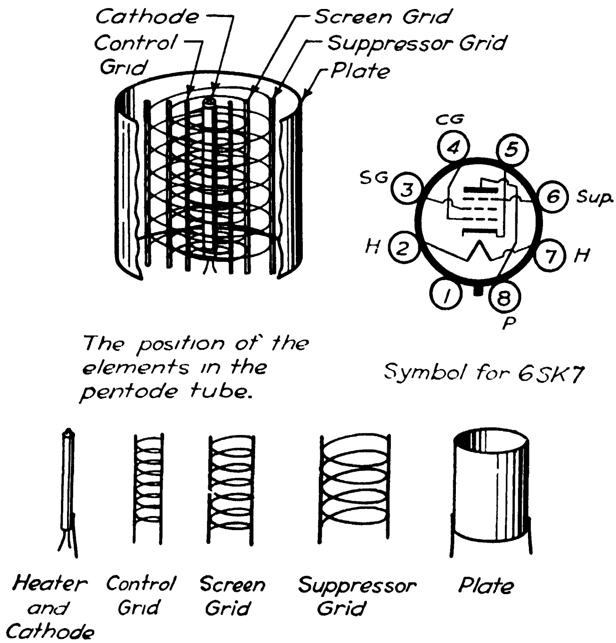


FIG. 298. These are the different elements of the pentode tube. The suppressor grid is connected to the cathode inside the tube.

pentode power-audio-amplifier tubes are the 42, the 6F6, and the 7B5.

Examine the pentode tube. Break open and examine a pentode tube. You find that it has a heater and cathode, a control grid, and a screen grid like the screen-grid tube. In addition, a suppressor grid is mounted between the screen grid and the plate (see Fig. 298). Its wires are more widely spaced than those of the screen grid or the control grid. It is sometimes connected to the cathode inside the tube.

How does the pentode work? A cathode, which may be a heavy filament or an indirectly heated cathode, supplies the electrons for the operation of this tube. When the plate is made positive by the B battery, it attacts electrons from the space charge surrounding the cathode, causing a current of electrons to flow through the tube.

Electrons, pulled toward the positive plate, are speeded up by the grid pull when the control grid is less negative. The negative grid slows up the electrons. The control grid, wound with closely spaced wires, is placed near the cathode. The close spacing of the grid wires gives great voltage amplification.

The plate in this tube is so far from the cathode that some of the electrons lose speed and never reach the plate. The screen grid, which is next to the control grid, is made positive by the B battery and pulls on the slowing-up electrons. The screen grid operates at as high voltage as the plate in this tube. These electrons, now speeded up, flash on to the plate.

Secondary Emission. When the electrons reach the plate, they are traveling so fast that they knock other electrons off the plate. The electrons knocked off the plate are called *secondary electrons*, and the action is known as *secondary emission*. These electrons would fly to the screen, which is positive enough to attract them, if the suppressor grid did not prevent this from happening.

The Suppressor Grid. This grid, between the plate and the screen grid, has its wires spaced farther apart than has either the control grid or the screen grid. The suppressor, made negative by its connection to the catnode inside the tube, repels the electrons knocked off the plate and so prevents secondary emission. In this way, the tube will handle a heavy current for power and will have high amplification as well.

What are the effects of secondary emission? Current will flow from the plate to the screen (secondary emission) of a screen-grid tube when the plate voltage becomes lower than the screen voltage. This occurs only on strong signals or when the plate voltage is very high. The secondary electrons cut down the strength of plate-current changes and reduce the power output of the tube. With secondary emission, stopped by the suppressor grid, high-voltage amplification is possible with a pentode tube.

PART 7: HOW THE BEAM POWER TUBE IS MADE

An ideal power-amplifier tube would combine the high mu of the voltage amplifier with the low-mu effect of being able to handle much current. These desirable features seem to be realized in the beam power tube.

This tube has high output, handling from about 50 to 75 milliamperes of current, and a mu of 8, which is relatively high for a power tube. It can often be connected directly to a detector. This eliminates one amplifier tube and combines in itself two stages of effectiveness. It is also a much-used oscillator tube for low-powered amateur transmitters.

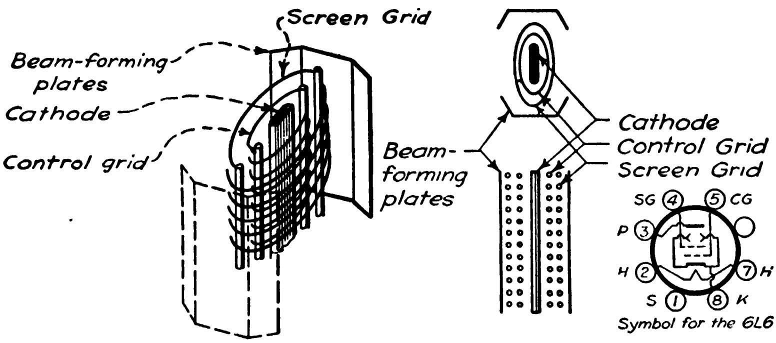


FIG. 299. The arrangement of the elements in the beam power tube. Note the beam-forming plates. Note also that the control-grid wires and the screen-grid wires are in line with each other.

What is the construction of beam power tubes? In Fig. 299 you note that this tube has a cathode with a large area from which to throw off electrons. The grid, placed near the cathode, has good controlling power over the electron stream.

The two beam-forming plates at the sides of the cathode are an unusual feature. These plates are attached to the cathode to make them negative. Another feature is the winding of the screen-grid wires so that each is directly in line with the wires of the control grid.

This tube is made either in glass or in metal envelopes.

Examine the schematic diagram of the base connections of a typical beam power tube. Figure 299 shows the schematic diagram for the 6L6 tube and the connections from the elements to the pins of its octal base. There are many other forms of beam

power tubes in the different tube series. Some of them are as follows:

6AC5	6V6	25L6
6AN5	7C5	35L6
6BK5	6L6	50L6

How does the beam power tube work? The electrons thrown off by the cathode are drawn toward the positive plate. The large quantity of electrons is concentrated into a narrowed beam, as shown in Fig. 300, by the repelling action of the negative beam-forming plates. As the electrons stream away from the cathode, the screen-grid wires, which are directly in line with the cathode wires, receive few electrons, because the electrons miss the screen-grid wires. The screen grid, with the same positive charge as the plate, adds its pull to the plate pull, and much current flows through the tube. The screen current is very low, because the electrons that normally were picked up by the positive screen in other pentodes now fly on past to the plate. This tube has high efficiency and high power output.

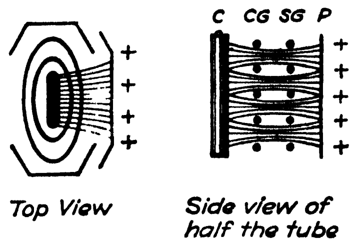


FIG. 300. How the beam is formed. The top view shows how the beam-forming plates, which are negatively charged, force the electron stream into a narrow beam. The side view shows how the wires of the con trol grid deflect the electron stream past the screen-grid wires.

Questions

1. In the pentode tube discuss the action of:

   a. The control grid, and state also the source of electricity for this grid.
   b. The screen grid, and state also the source of electricity and charge on it.
   c. The suppressor grid, and state also the source of electricity and charge.

2. What is secondary emission, and what causes it?
3. Why is the control grid unevenly spaced on supercontrol tubes?
4. Name and state the purpose of each part in a beam power tube.

Technical Terms

amplification—The ability of small grid-voltage changes to make changes in the plate current as great as those which would be caused by large changes of plate voltage.

amplification factor—An engineering term for a number which is found by dividing a change in plate voltage by a change in grid voltage, with the plate current remaining the same.

cathode—The coated metal sleeve which, when heated by the heater filament, throws off electrons. The filament in this tube is only a heater element, while the cathode is the electron supplier.

DX—The amateur abbreviation for distance; DX reception means long-distance reception.

G_m—The symbol for mutual conductance.

key—The projection on the aligning plug which fits into the socket, so that the tube can be inserted only in the correct way.

loctal—A type of tube and socket arranged with a groove and spring which grip the plug and hold the tube in the socket, so that vibration will not loosen the tube.

mho—The word *ohm* spelled backward. The mho is the symbol for conductance, or the ease with which a current flows through a resistance.

mu—The Greek letter used as a symbol for amplification factor.

mutual conductance—A term used to describe the amplifying ability of a tube. Mutual conductance equals amplification factor divided by plate resistance.

octal—A word meaning *eight.* An octal tube has an eight-pin base and socket.

plate resistance—The opposition to the flow of current between cathode, or filament, and plate.

screen grid—A second grid, between the control grid and the plate.

secondary emission—Electrons dislodged from the plate by speeding electrons from the cathode. Secondary emission is often produced by excessive plate voltage.

suppressor grid—A third grid, placed between the screen grid and plate in a pentode tube.

thermal inertia—Heat laziness. The heavy filament and the bulky cathode heat slowly when the set is first turned on and remain at the same heat. Their heat changes too slowly to be affected by the changes of the alternating current.

CHAPTER 16

BASIC RECEIVING CIRCUITS USING ALTERNATING-CURRENT TUBES

You will find many new and fascinating possibilities when you use the alternating-current tubes that you studied in the last chapter in receiving circuits. By selecting tubes with high amplification factors and increased sensitivity, you will be able to build sets and to assemble and operate many kinds of receivers which will bring in distant stations that you never received before. You can set up nearly any standard circuit you desire. You can also assemble the different basic circuits into many new combinations.

When you study the applications of the alternating-current tube, you will confine yourself to the basic circuit. Then in later chapters you can try your hand at different combinations of the basic circuits in practical sets.

The basic circuits using alternating-current tubes are the same as those using direct-current tubes, but the connections to the tube filaments, or heaters, are different. The alternating-current tube circuits use the same tuning coils and condensers that you used with the direct-current sets. You can use transformer coupling between some alternating-current tubes, but for others you must use resistance coupling. The B voltages and filament voltages required depend on the type of tube you are using.

You will learn the following things in this chapter:

Part 1: How the Altêrnating-current-tube Detector Circuit Is Different
Part 2: How to Build a One-tube Alternating-current Detector Set, Using the 6C5 Tube
Part 3: How the Alternating-current Audio Amplifier Is Built
Part 4: How to Use the Power-audio-amplifier Circuit
Part 5: How the Push-pull Power Audio Amplifier Is Built
Part 6: How Power Is Transferred between Stages—Coupling
Part 7: How the Radio-frequency Amplifier Is Built
Part 8: How to Build a Single-control Receiver
Part 9: The Power Detector
Part 10: Volume-control Circuits and How They Operate

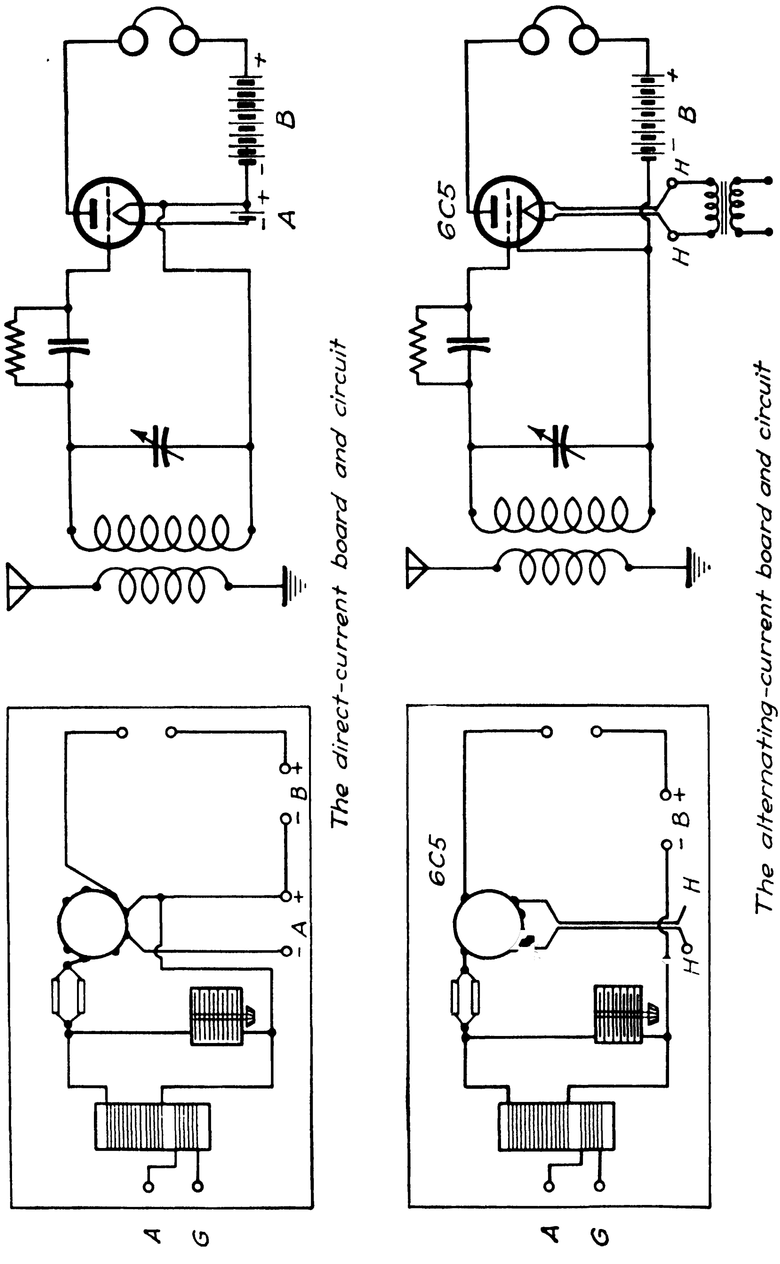


FIG. 301. Compare the detector circuit for the alternating-current tube with the same circuit using a direct-current tube.

PART 1: HOW THE ALTERNATING-CURRENT-TUBE DETECTOR CIRCUIT IS DIFFERENT

The direct-current-tube detector circuit and the alternating-current-tube detector circuit are very similar. Figure 301 shows circuits for the simple direct-current detector set and for the corresponding detector set using an alternating-current tube. The antenna coil and the antenna-ground connections are the same. The receiving transformer and the tuning condenser used in the tuning circuits of each set are the same. The grid leaks and condensers are of the same size on both sets.

The tube and the heater circuit. *The Socket.* An octal wafer socket is used for the 6C5 tube. The new pin is for the cathode connection. There are no 4 and 6 pins on this tube.

The Heater Circuit. The heater current is obtained from a 6.3-volt step-down secondary on a power transformer. Number 16 wire, or larger, is used in the heater circuit, so that the voltage at the tube socket will be of the correct value. If the heater voltage is low, too few electrons are thrown off the cathode and the set will not operate properly. For this reason the wires from the filament-heating transformer to the set are kept as short as possible not over 24 inches from the power transformer to the tube. The voltage drop in longer heater wires is excessive.

The Plate Circuit. The plate circuit and the B supply are the same in sets using direct-current and alternating-current tubes.

Question

What changes are made in the circuit to convert a direct-current detector into an alternating-current detector?

PART 2: HOW TO BUILD A ONE-TUBE ALTERNATING-CURRENT DETECTOR SET, USING THE 6C5 TUBE

How to Build and Wire the Set

This is the same board and circuit that was used for the direct-current detector set. The only new parts needed are an octal wafer socket and a 6C5 tube (see Fig. 302). The following are changes in the wiring from a direct-current set to the alternating-current set:

The antenna circuit. Make no changes (see Fig. 303).

The grid circuit. Connect the grid return to the cathode terminal of the tube socket (pin 8).

The cathode wire. Connect a wire from the B-negative connections to the cathode terminal on the tube-socket base (pin 8).

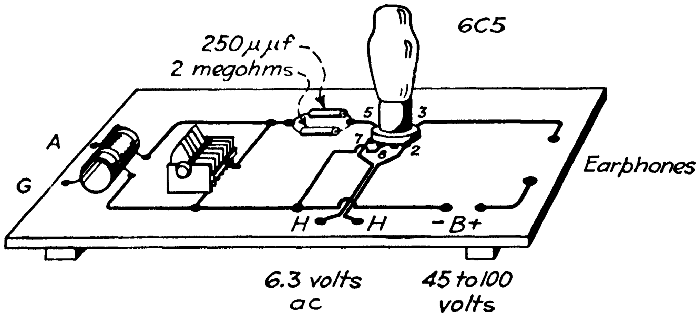


FIG. 302. The board layout for the 6C5 grid-condenser grid-leak detector circuit.

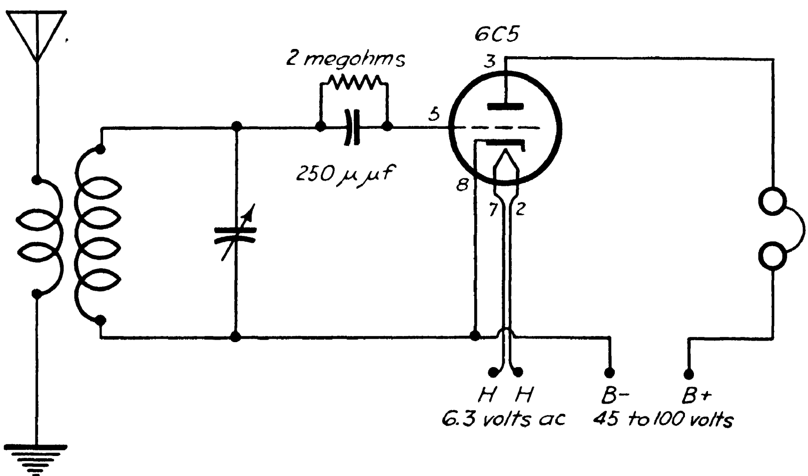


FIG. 303. The schematic circuit for the 6C5 detector.

The heater circuit. Use extension cord or other rubber-insulated wire, not smaller than No. 16 and long enough to reach from the heater terminals on the tube socket to the board binding posts.

How to Operate the Set

Connect the antenna and ground. Connect the antenna and ground lead-in wires to the antenna and ground posts on the set board.

Connect to the filament transformer. Connect a short piece of extension cord from the 6.3-volt alternating-current posts on the set to the 6.3-volt terminals on the filament transformer, or power supply. This cord should not be over 2 feet long.

Plug the transformer, or power supply, into an outlet to turn on the set.

Connect the B battery and phones. Connect the B-negative wire first.

Connect the B-positive wire to the 45-volt tap on the B battery. Also try higher plate voltages.

Connect the earphones, and the set is ready to operate.

Tune in a station. The 6C5 tube requires no change in the operation of the set at all. The process of tuning is the same as for the direct-current receiving sets. Adjust the tuning condenser until the desired station is heard the loudest. The tube is somewhat more efficient than the 1LE3, and the volume should be better.

Other tubes you can use. You will find the 6J5 a good detector tube. It may be used in the same circuit as the 6C5 tube. The 6C5 is also a good tube to use in audio-amplifier circuits.

Why It Works

The explanation of the operation of this circuit is covered in discussions of other circuits you have studied.

Tuning. Tuning was explained in Chapter 11. See also the explanation for tuning the one-tube detector set in Part 1 of Chapter 12.

Cathode. The purpose of the cathode is explained in Part 2 of Chapter 15. See the explanation of alternating-current tubes in alternating-current receiving sets.

PART 3: HOW THE ALTERNATING-CURRENT AUDIO AMPLIFIER IS BUILT

You will now learn how to change the direct-current set into an alternating-current amplifier using the 6C5 tube.

The Set Wiring

The 6C5 audio-amplifier circuit board is similar to the 1LE3 audio-amplifier board and circuit. Note the changes in wiring for the new tube.

Heater wires. Run two wires to the H posts on the tube socket, pins 2 and 7 (see Figs. 304 and 305).

The tube socket. Use an octal wafer socket.

The audio transformer. The connections will be the same as on the direct-current board, except for the grid bias. A similar transformer may be used.

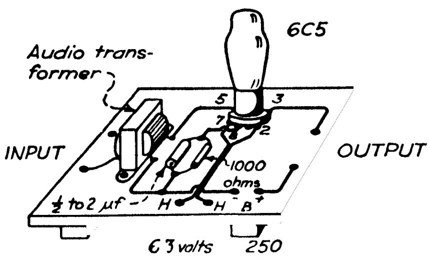


FIG. 304. The board layout for the 6C5 audio-amplifier circuit.

The grid bias. The bias is obtained by means of a resistor in the cathode lead. Each different B voltage requires a different resistor size for best results. These grid-bias voltages may be found in any standard tube chart. See Radio-tube Characteristics Charts, pages 668 693. A 1000-ohm resistor will give fair results.

Shunt the bias resistor with a fixed by-pass condenser of ½ to 2 microfarads capacity. When the bias resistor is shunted by a condenser, the set will play more loudly, and distortion will be reduced or eliminated.

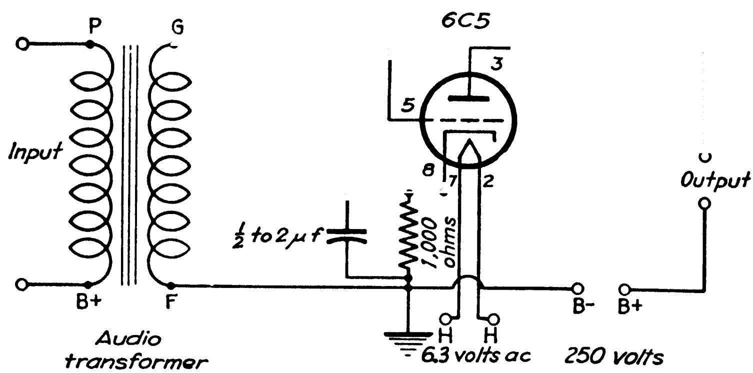


FIG. 305. The schematic circuit for the 6C5 audio amplifier.

The plate circuit. Make no change.

The heater circuit. Use a parallel pair of wires for the connection from the 2 and 7 pins on the socket to the H board terminals (6.3 volts).

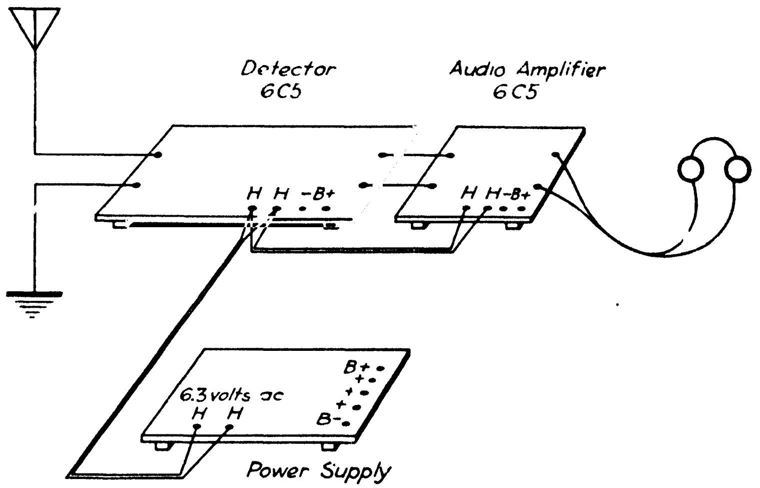


FIG. 306. Connect wires from the 6.3-volt terminals on the power supply to the heater terminals on the detector and audio-amplifier set boards.

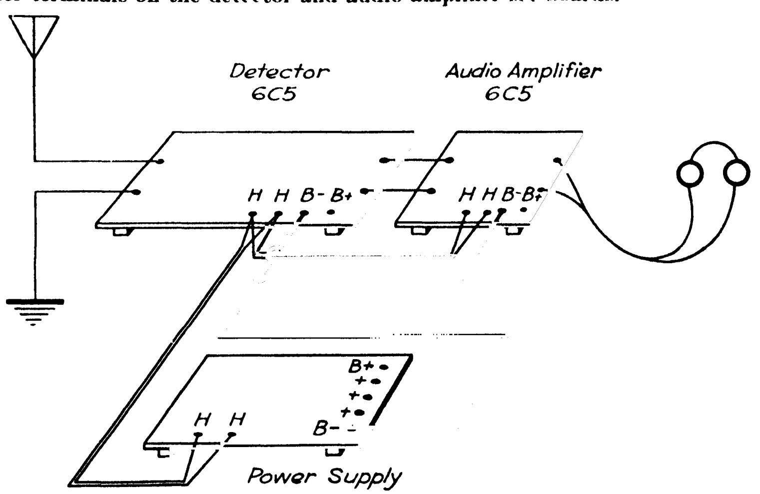


FIG. 307. Now connect the B-minus wire from the power supply to one board, then connect a B-minus wire between the two boards.

How to Hook Up the Amplifier

Step 1. Connect the detector and amplifier board together. Attach the antenna and ground wires to the detector board (see Fig. 306). Attach earphones to the amplifier.

Run heater wires from the power-supply board to the detector and amplifier boards.

Step 2. Attach the B-minus wire from the power-supply board to both sets (see Fig. 307).

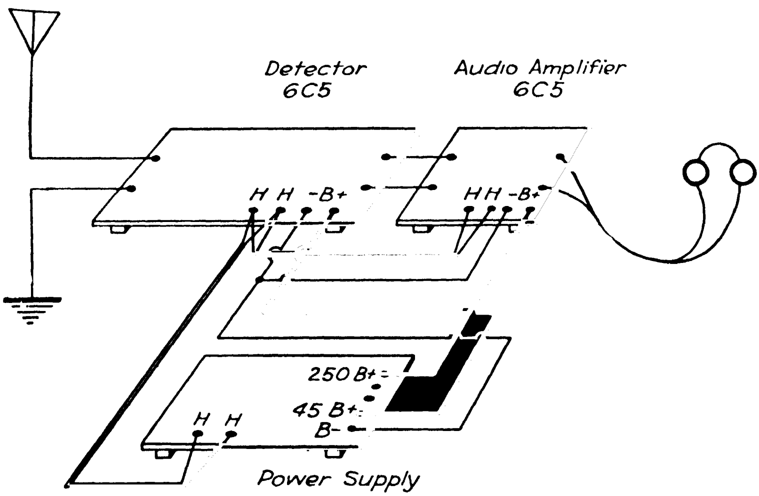


FIG. 308. Connect a wire from the B-plus, 45-volt tap on the power supply to the detector. Then connect the 250-volt tap on the power supply to the amplifier board.

Step 3. Run a wire from the 45-volt tap on the power supply to the detector B-plus post. Run a wire from the 250-volt tap to the post connected to the amplifier plate (see Fig. 308).

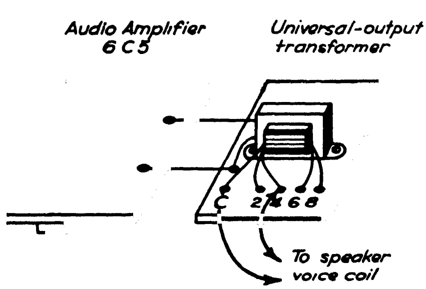


FIG. 309. Connect an output transformer to the output of the power audio amplifier. This shows a universal output transformer with a tapped secondary. You can try the taps and find which gives the best impedance match between the tube and the speaker.

Step 4. Check the connections carefully. Have the instructor approve them before you turn on the set. Then turn on the power, and tune the set to a station.

Step 5. Replace the earphones by a universal output transformer and a dynamic speaker (see Fig. 309).

Change the connections on the secondary of the output transformer until you get the best music quality.

Why It Works

Grid bias prevents distortion. Any effect that changes the wave form of signals that reach the grid is heard in the phones or the speaker as distortion. It is caused by changes in the wave shape of the signals as they pass through the set. You will better understand how grid bias prevents distortion by first operating a set

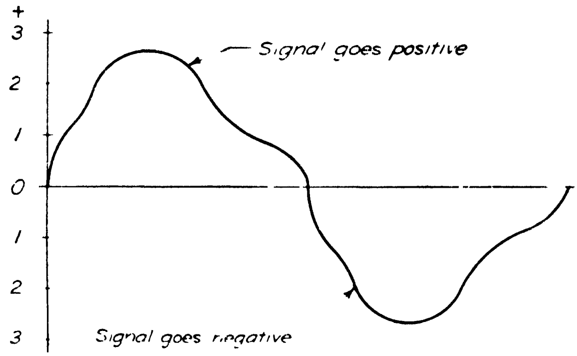


FIG. 310. This is the wave shape of the signal that pushes electrons on and pulls them off the grid.

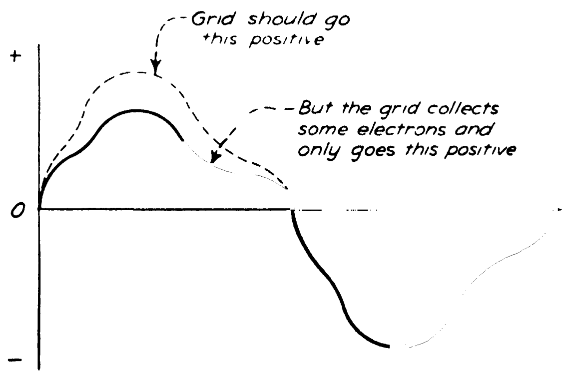


FIG. 311. When the grid goes positive, it collects some electrons from the space charge. The wave shape shows that it does not go positive enough so that the sound is distorted.

without grid bias. It is then easy to hear the distortion and to note the improvement when the correct bias is added.

What will happen when no negative bias is used? During every positive cycle, the signal pulls electrons off the grid and makes it slightly positive (see Fig. 310). But the positive grid attracts electrons from the filament. These electrons on the grid make it less positive than it should be in order to follow the volt-

age changes of the incoming signals (see Fig. 311). These extra electrons, collected by the grid, change the shape of the signal wave on the grid. As a result, the wave shape of the plate current changes and the sound is distorted. The music is of poor quality.

You can improve the music quality by placing a negative bias on the grid. By *negative bias*, we mean a steady voltage that forces electrons onto the grid and keeps it negative. Then even the swing of a strong signal in the positive direction will make the grid less negative, but it will still remain negative. The negative grid will collect no electrons from the filament, and the music will be clear and undistorted.

Why does grid bias clear the music? The tube manufacturer has made extensive tests to find the best operating voltages for tubes, and he shows these figures in the tube charts.

The 6C5 needs a negative bias of 8 volts on the grid for a plate voltage of 250 volts to keep the music clear. This is shown in the negative-grid-volts column in the tube chart. See Selected Tube List, pages 668–669.

Now suppose a radio wave from a distant station reaches the antenna and, as a result, the receiving set causes a signal of 3 volts to appear on the amplifier grid. This will make the grid alternately 3 volts positive and 3 volts negative when no bias is on the tube.

But we know that the music will be distorted, because the grid becomes positive during part of each cycle.

Now, if you connect the 8-volt negative bias to the grid, the music immediately clears up and also becomes louder.

The wave picture in Fig. 312 shows what happened. The 8-volt negative bias sets a new zero operating point shown here as a dashed line. When the signal is 3 volts positive, the grid is only 5 volts negative [-8 volt bias $+$ $(+3)$ volt signal $=$ -5 volts on grid]. But when the signal is 3 volts negative, the grid is 11 volts negative [$-8 + (-3) = -11$].

The music is clear because no change occurs in the wave shape. It is louder because both positive and negative loops of the alternating current in the plate circuit are at full strength.

What is the effect on the plate current? Remember that changes in plate current produce the sound in the speaker. A signal producing a 3-milliampere change in plate current produces

just as loud a sound when the steady value of plate current is 10 milliamperes as when it is 50 milliamperes.

In the example above, you had a 6-volt change on the grid, 3 volts negative and 3 volts positive. When the starting point was zero volts on the grid at no signal, you had less than a 6-volt change, with *distortion*, because enough electrons were attracted from the filament to reduce the positive swings by 0.5 volt. This will make the grid 2.5 volts positive and 3 volts negative, which

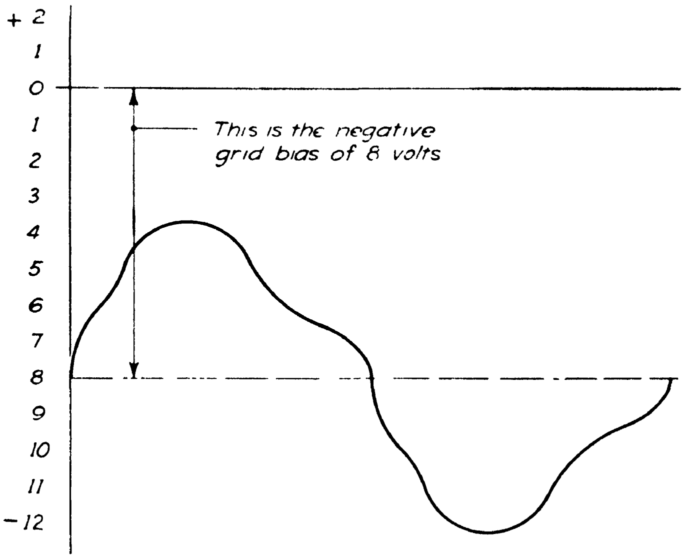


FIG. 312. Here a bias of 8-volts negative is placed on the grid. Now the grid simply goes more or less negative. It does not become positive at all. Note that the less negative part of the wave now has no distortion.

produces distortion. But with the 8-volt negative bias, you had a full 6-volt change (negative 5 to negative 11), with no distortion.

The plate current was weaker with the negative bias, but the music was equally loud, because the same change in plate current occurred each time.

The cathode resistor is the source of grid bias. When you connect a 1000-ohm fixed resistor in the cathode lead (see Fig. 313), you get a negative voltage of 8 volts between the grid of the 6C5 and its cathode. How does this happen? Trace the drift of electrons through the plate circuit (see Fig. 314). As they leave the B battery, or power supply, and reach *A*, they meet the hindering effect of the resistor, and some voltage is used as heat in forcing

electrons through the resistor *AB*. You can measure the voltage drop across the resistor with a high-resistance voltmeter.

Note that the end of the resistor is connected directly to the grid through the secondary coil of the amplifying transformer. Since there is little or no flow of electrons through the coil, there is practically no change in voltage across the coil. Therefore, the

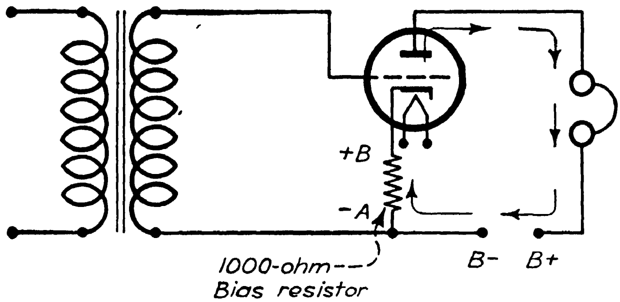


Fig. 313. When you connect a fixed resistor in the cathode lead, you get a negative voltage on the grid.

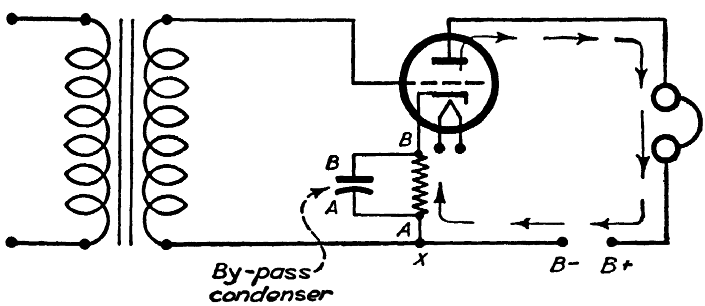


Fig. 314. The by-pass condenser is a good path for the electrons that are being pushed round by surges in the plate circuit. They can push past the grid resistor without affecting the voltage on the grid.

grid is 8 volts more negative than the cathode, because of the 8-volt drop that the plate current produces in the resistor. So we say the grid has an 8-volt *negative bias*.

How do you calculate the grid bias? Suppose you want to find the resistor size that would produce the negative bias shown in the tube chart. You find the value of the resistor by using Ohm's law. Here is the method:

Step 1. Find the required negative bias in the Radio-tube Characteristics Charts, pages 668–693, for the plate voltage you

expect to use. The chart for the 6C5 tube shows that this tube requires a bias of minus 8 volts for 250 volts on the plate.

Also find the plate current that is supposed to flow when you have the required values of plate voltage and negative bias. The chart for the 6C5 tube shows that 8 milliamperes flow when the plate voltage is 250 and negative bias is 8 volts.

Step 2. Use Ohm's Law.

$$I = \frac{E}{R} \quad \text{basic Ohm's-law formula}$$

$$R = \frac{E}{I} \quad \text{rearranged Ohm's-law formula}$$

where R = the size of the resistor in ohms
E = the bias voltage given in the tube chart
I = the current (in amperes) that flows through the resistor. Here it is the plate current, 8 milliamperes, or 0.008 ampere.

Step 3. Substitute the bias and plate current from the tube chart, and work out the answer.

$$R = \frac{8 \text{ volts}}{0.008 \text{ ampere}}$$

$$= \frac{8}{\frac{8}{1000}} = 8 \times \frac{1000}{8} = 1000 \text{ ohms}$$

What is the purpose of the by-pass condenser? *Plate Current with No Signal.* When no signal is on the grid, there is a steady plate current of 8 milliamperes. The steady voltage on the grid (the grid bias) keeps the electron drift through the plate circuit steady.

Plate Current with a Signal. A signal makes the grid alternately more and less negative. When the grid is *less* negative, the plate current is stronger than when there is no signal. When the grid is *more* negative, the plate current is weaker than when there was no signal.

As the plate-current strength changes, surges of electrons reach the resistor at A in Fig. 315. These surges also change the voltage on the grid (without a by-pass condenser). These changes in voltage on the grid interfere with and partly cancel the surges that the signal causes on the grid. Only the changes in voltage due

to the signal should be on the grid if the resulting weakening in the strength of the plate-current changes is to be avoided.

Connect a large by-pass paper condenser across the grid-bias resistor, as in Figs. 314 and 315, and you can keep these unwanted surges from affecting the grid.

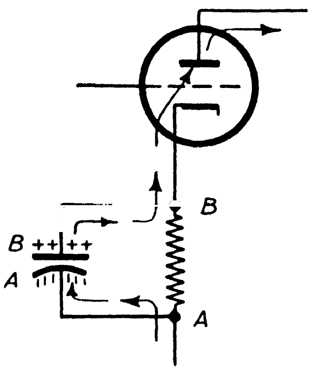


FIG. 315. When electrons are pushed on side *A* of the condenser, they push electrons off side *B*. These electrons from *B* go on through the tube.

Now, when a surge reaches *A*, the extra voltage forces electrons on side *A* of the condenser instead of through the bias resistor. Electrons on side *B* move on to the cathode and through the tube (see Fig. 315). The only bias voltage is that produced by the steady portion of the plate current. Then when the surge dies down, electrons on *A* push out of the condenser without going through the resistor to the tube. Thus the plate-current surges are by-passed around the bias resistor, so that no alternating bias voltage occurs. Because the bias voltage on the grid is steady, no distortion occurs and the music is stronger and clearer.

PART 4: HOW TO USE THE POWER-AUDIO-AMPLIFIER CIRCUIT

Overloading produces distortion. The 6C5 tube is overloaded when you try to use it as a power amplifier. Too much signal on the grid drives it positive, introduces distortion, and spoils the fidelity of the signals, just as distortion is produced when you try to operate without grid bias. A power-amplifier tube should be used.

Audio-amplifier tubes, such as the 6F6, 6V6, and 6L6 power tubes, deliver enough power to operate a speaker with good fidelity.

Power tubes produce more volume. A power tube, which is designed to handle more current in the plate circuit than a 6C5, will produce much louder signals without distortion. The heavier plate current is needed when a dynamic speaker is used. The 6C5 tube will handle about 8 milliamperes of current, while the 6F6 tube (a good power tube) will handle around 30 to 35 milliamperes without distortion. These tubes take the place of the 1LE3 tube

that you used in the direct-current sets. The 6F6 power tube will handle even more current, but the quality of the signals produced by the 6F6 is not as good as that produced by the 6C5 tube. The 6C5 is a low-mu tube, and the 6F6 is a high-mu tube with considerable current amplification.

You learned, when you operated audio amplifiers in Chapter 12, that you could make the music louder by adding a second audio amplifier to drive the dynamic speaker. You will find that the 6C5 tube used as a power audio amplifier will increase the music volume, but not as efficiently as a power tube. This is because the 6C5 is overloaded when you try to use it as a power audio amplifier. Too much signal on the grid drives it positive, introduces distortion, and spoils the fidelity of the signals, just as distortion is produced when you try to operate the tube without grid bias.

How is the 6C5 used as a first audio amplifier? A better scheme is to use the 6C5 as a first audio amplifier. You may do this by coupling it between the detector and the power tube. In this way, the signal voltages delivered by the detector to the grid of the 6C5 are amplified, so that the signal voltages are much stronger when delivered to the grid of the power audio amplifier.

The power tube is designed to handle larger signal voltages on its grid and to handle heavier plate currents, so that no distortion will occur because of overloading. The heavy plate current will drive the dynamic speaker through the output transformer much more effectively than will the weaker plate current of the 6C5.

Questions

1. Electrons from the B battery have a choice at point *X* (Fig. 314) of flowing in two directions. Which path will most of them take? Give reasons for your answer. Explain why any will flow in the other direction.

2. Is the grid kept slightly positive or negative in this circuit?

3. If there is no condenser connected around the cathode resistor, where will the surge of electrons from the B negative try to go when the grid suddenly decreases the current from the cathode to the plate?

4. When the by-pass condenser is in the circuit, show the two possible paths for the electrons when the grid suddenly decreases the current from the cathode to the plate.

5. Explain why the electrons choose one of these paths in preference to the other.

6. Explain why the wires carrying alternating current to the filament are twisted.

7. Compare the advantages of a negative grid bias with a positive grid bias.

8. How can you obtain a negative grid bias without using a C battery?

9. Compute the size of bias resistor to use when a tube needs 7 volts negative bias on the grid and carries 2.5 milliamperes of plate current.

10. State briefly the purpose of the by-pass condenser.

Using a Pentode Tube in the Power Audio Amplifier

How to build and wire it. Build this amplifier on a small base board. Arrange the parts as shown in Fig. 316. Wire it as shown in the schematic diagram, Fig. 317. Place clips, or connections, so that you can try different sizes of coupling condensers and load resistors in the coupling circuit. Two clips also are provided in the cathode lead so that you can try different bias resistors and by-pass condensers.

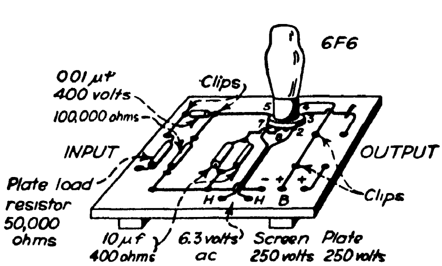


FIG. 316. This is the board layout for the power audio amplifier using a pentode tube.

The two clips in the screen circuit allow you to get different screen voltages by means of a dropping resistor or by connecting the screen circuit to a tap on the power supply.

How to operate it. Connect a coupling condenser of 0.01 microfarad capacity and a grid resistor of 100,000 ohms to the grid-circuit clips. Connect a 400-ohm bias resistor and a 10-microfarad 50-volt by-pass condenser, as shown in Fig. 316, to the clips provided in the cathode circuit. Figure out the bias-resistor size for the tube you use from the bias voltage, plate current, and screen current shown in the tube chart. You can find the current through the bias resistor by adding together the plate current and the screen current. Connect a plate load resistor of 50,000 ohms across the *input* clips.

After you have operated the set, experiment with different resistor and condenser sizes to see their effect on music quality. Use the same value of screen-grid voltage that you use for the plate voltage, that is, 250 volts on each.

How to Use the Power Audio Amplifier in a Circuit

Step 1. Connect a 6C5 detector, a 6C5 audio preamplifier, and the new power amplifier, as shown in Fig. 318. Connect the antenna and ground to the detector. Connect a universal out-

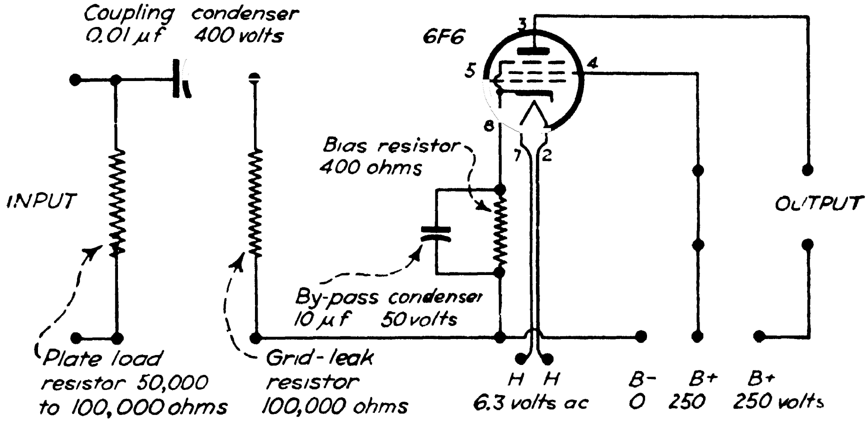


FIG. 317. The schematic diagram for the power audio amplifier using a pentode tube.

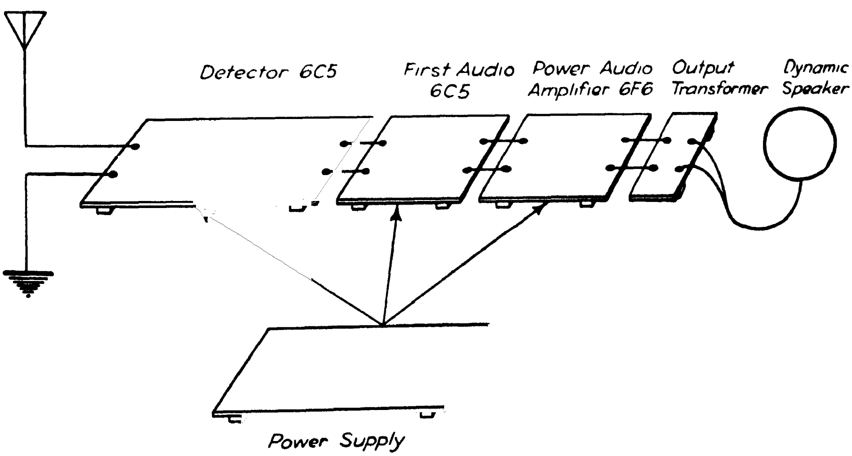


FIG. 318. Here is a three-tube set which will play well. The music will be of reasonable quality and the volume good.

put transformer and a dynamic speaker to the output posts of the power amplifier.

Step 2. Run the heater wires from the power supply to each set board. Turn on the power supply to see if all the tubes heat up. *Then turn it off* (see Fig. 319).

Step 3. Connect together the B-minus posts of all boards. Run a wire from the B-minus on the power supply to the B-minus on any one of the three set boards (see Fig. 320).

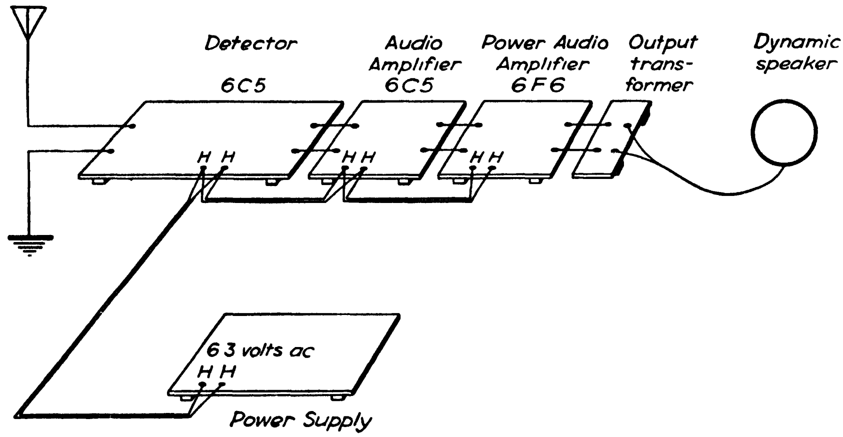


FIG. 319. Attach wires and test the heater-filament supply.

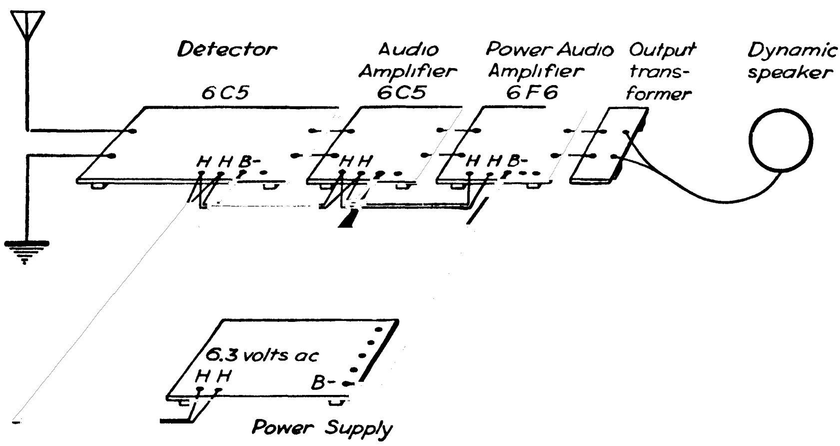


FIG. 320. Connect the B-negative wires.

Step 4. Connect the high voltage from the power supply to the B-plus posts on both amplifier boards.

Run a wire from the 250-volt post to the screen-grid post on the power audio amplifier. Or you can connect a wire between the screen and plate B-plus posts on the board (see Fig. 321).

Step 5. Check the B-plus wiring carefully. Also have the instructor check it before turning on the power supply.

Step 6 Turn on the power supply, tune the set to a station, and the set should play.

Why It Works

You learned the operating principles of the 6F6 pentode tube in Chapter 15, "Alternating-current Receiving Tubes." The operation of the rest of the circuit has been explained earlier in this chapter.

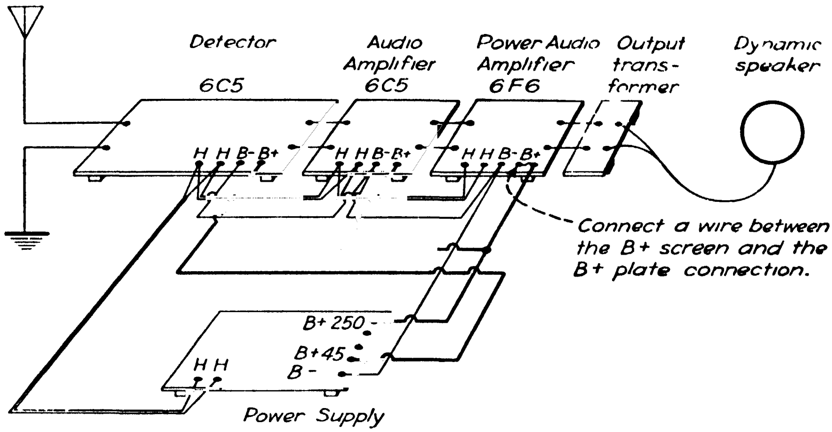


FIG. 321. Connect the B-plus wires with the terminals having voltages shown and the set is ready to play.

PART 5: HOW THE PUSH-PULL POWER AUDIO AMPLIFIER IS BUILT

Why Push-pull Amplifiers Are Used

The purpose of any audio amplifier is to increase the volume of sound produced by the set. It does this by amplifying voltages, thus causing plate-current changes to produce sound. But when you try to increase the power output of a triode power tube by raising the B voltage, you may overheat and damage it. You also overload the tube and produce distortion in the music by applying too large a signal voltage on the grid.

One remedy is to use a pentode power tube. The pentode needs less grid voltage from the preceding audio-amplifier stage. The beam power tube will handle still more power. The *push-pull circuit,* which uses two tubes, is still more efficient. With it you can obtain much greater power and also diminish the distortion. The

tubes tend to run much cooler in this type of circuit. Both tube and circuit design affect the operation of the amplifier.

There are several versions of push-pull circuits, some using transformer coupling, others, called *phase inverters*, using resistance coupling. The phase-inverter circuit is explained in Chapter 19, "Public-address Units."

Push-pull Power Audio Amplifier Using 6F6 Tubes

How to wire the circuit. Mount the parts on a small board, as shown in Fig. 322. A special input transformer and an output push-pull transformer are needed with this circuit. Connect one end of the input-transformer secondary to the grid of one amplifier

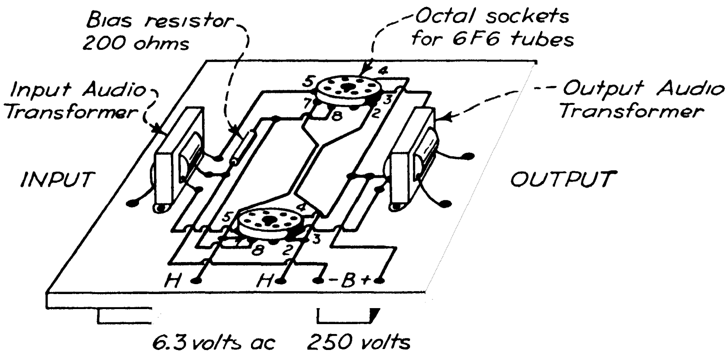


FIG. 322. Lay out the parts for the push-pull amplifier as shown here.

tube and the other end to the grid of the other amplifier tube (see Fig. 323). Connect the plates of the power tubes to the two ends of the primary of the output transformer. The bias resistor used in the push-pull circuit should have half the resistance you would use for the same tube in a single-tube circuit. Distortion and loss of power will occur if the bias is incorrect. No by-pass condenser is required for the grid-bias resistor.

How to operate it. Turn on the heater and B power. The set is in operation. There are no adjustments for this circuit.

How it works. The input coupling transformer is connected to the plate circuit of the first audio-amplifier stage to transfer the signal to the grid of the push-pull amplifier, as shown in Fig. 323. The audio signal from the detector has been amplified by the first audio amplifier and is delivered through the input coupling transformer to the grid circuit of the push-pull stage.

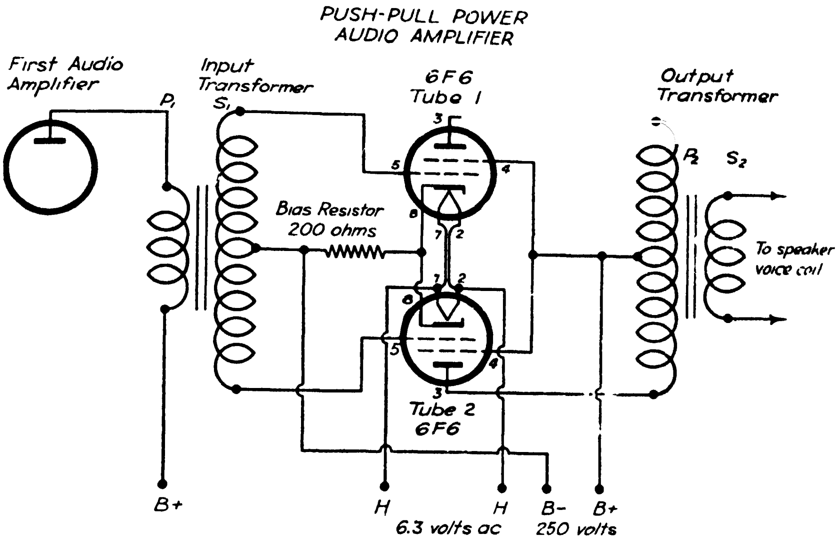


FIG. 323. The schematic circuit diagram of the push-pull power audio amplifier.

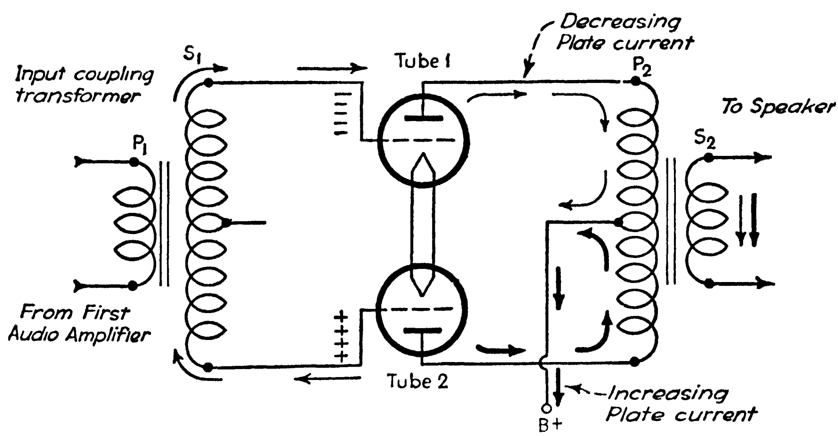


FIG. 324. When the electrons surge *on* the grid of tube 1, the plate current through this tube *decreases*. At the same time the grid of tube 2 is becoming positive and the plate current through this tube is *increasing*.

Now follow the effect that electron surges in the first audio-amplifier plate circuit have in the push-pull amplifier circuit (see Fig. 324). The varying strength of the plate current in the first audio amplifier sets up an alternating voltage in the secondary of the input coupling transformer P_1. This drives electrons on the grid of tube 1 and at the same time draws electrons off the grid of

tube 2. Thus the plate current of the tube whose grid is being made *more* negative is weakened. But, at the same time, the plate current of the tube whose grid is being made *less* negative is becoming stronger.

The Grid Bias. The bias voltage put on both grids by the grid-bias resistor makes both grids negative. As explained earlier, the grids must never become positive, or they will draw current and will distort the signals. Now notice the action of the plate current from both tubes in the output transformer.

The Effect of a Surge of Increasing Strength. When a surge of electrons flows through the primary P_1 of the input coupling transformer (Fig. 324), it causes electrons to surge through the secondary, as shown by the arrows, while the primary surge is *growing in strength.* Electrons surge to the grid of tube 1 and make it more negative. The negative grid reduces the flow of electrons through tube 1, and a current of *decreasing strength* flows, as shown by the light arrows in Fig. 324.

At the same time, the secondary pulls some electrons off the grid of tube 2, making its grid less negative. The less negative grid allows a current of *increasing strength* to flow through tube 2. The plate current of tube 2 flows through the primary of the output transformer and back through the center-tap connection to the B battery, as shown by the heavy arrows.

The Current in the Output-transformer Secondary S_2. When the current flow through tube 2 (Fig. 324) is increasing in strength, it induces a voltage in secondary S_2, as shown by the heavy arrow.

At the same instant, the current through tube 1 is *decreasing in strength.* It induces a voltage in S_2 that adds to the voltage induced by tube 2.

When the surge of electrons through P_1 reverses, as shown in Fig. 325, the increasing current through tube 1 induces a voltage in S_2, as shown by the heavy arrows. At the same time, the decreasing current through tube 2 induces a helping voltage, as shown by the light arrows. Again, both voltages in S_2 add.

Tube Action. The two tube grids switch the plate current from one tube to the other, so that much current flows through one tube during a half cycle. During the other half cycle, the other tube works. A much higher power output is possible with this circuit than with a straight single-tube amplifier. Higher B voltage can

be used without overheating the tube plates. Heavy plate current flows only for a half cycle, and the plate cools during the other half cycle. A half of each input surge cuts down the current flow through one tube and allows much current to flow to the plate of the other tube.

The Second Harmonic. Harmonics are developed in nearly all vacuum-tube circuits. The *second harmonic* is twice the fundamental frequency. The fundamental is called the *first harmonic.* A 500-cycle note will have a second harmonic of 1000 cycles. It

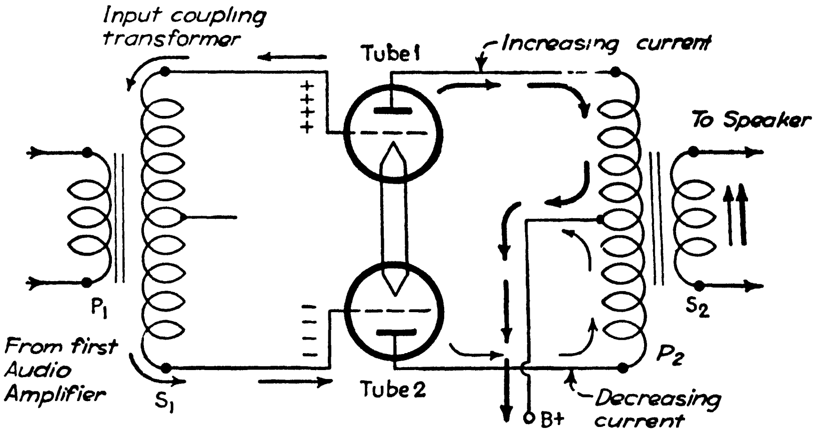


FIG. 325. When the voltage of the grid circuit reverses, the plate current through tube 1 *increases* and that through tube 2 *decreases*. Note the effect in each case on the current induced in the secondary of the output transformer.

will have many other harmonics which are so weak that they may be disregarded.

The second harmonic is the strongest. It stresses frequencies double the frequency of the signal that is being amplified.

In the push-pull amplifier the second harmonic is eliminated by the circuit.

Questions

1. What causes the grids of the push-pull circuit to remain negatively charged?

2. Does the current always flow in the same direction through the secondary of the coupling transformer?

3. Does a strong current flow through both tubes at the same time?

4. Does the current always flow in the same direction through the center tap of the primary of the output transformer?

5. Why can a much higher power output be used with a push-pull circuit than with a single-tube amplifier?

How to hook up a push-pull amplifier. When you hook up a push-pull amplifier, you must have enough voltage to drive its grids, so that this circuit will develop all the power it is capable of producing. For this reason you will need an amplifier stage ahead of the push-pull stage. As shown in Fig. 326, this voltage is provided by the 6C5 audio-amplifier stage ahead of the push-pull stage.

Step 1. Connect three circuit boards together. Use a 6C5 detector, a 6C5 first audio amplifier, and a 6F6-6F6 push-pull amplifier (see Fig. 326).

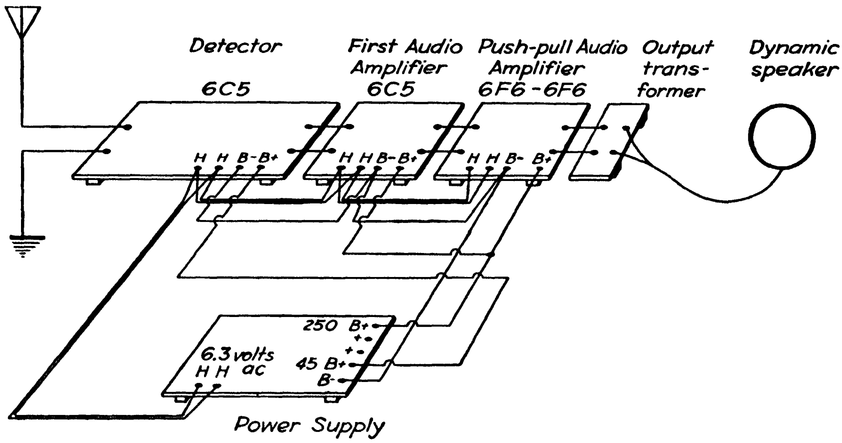


Fig. 326. Hook up a push-pull amplifier. Connect the set boards together.

Step 2. Connect the antenna and ground wires to the detector board. Connect a dynamic speaker to the push-pull amplifier through an output transformer.

Step 3. Connect the heater terminals on the set boards in parallel to the power supply. *Turn on* the power supply to test the connections. *Turn off* the power supply after this test is completed.

Step 4. See that the power supply is *off*. Connect the B-negative wire to all boards.

Step 5. Connect a separate B-plus wire to each board. Use the voltages shown in the diagram in Fig. 326.

PART 6: HOW POWER IS TRANSFERRED BETWEEN STAGES—COUPLING

You learned earlier that some form of coupling was needed between stages of a radio set. You may have noted that the

detector was coupled to the audio amplifier by means of an audio transformer. Then you noted that the first audio amplifier was coupled to the power audio stage by a transformer or by resistance coupling (a condenser and resistors). Also, the power audio amplifier was coupled to the speaker by an output transformer. You will learn in Chapter 19, "Public-address Units," about a phase-inverter coupling system (a condenser-resistor network).

When you examine the radio-frequency amplifier to be described next, you will find a different kind of transformer used for coupling.

While the reasons for the engineering design of these different coupling methods are beyond the scope of this book, some general statements can be given to help explain the background principles of coupling.

Before you go further, you will need to know something about power in an electrical circuit.

How does power affect the electrical circuit? When you studied Ohm's law, you found that voltage, current, and resistance were all tied in together. When any one of these changed, the others were also affected. Power now adds a new factor that changes as voltage, current, or resistance changes.

When you attach an A battery, a flashlight cell, or a No. 6 dry cell to a tube, power is consumed. You *see* the result of power applied in overcoming resistance as the glow of the heated filament. You can *feel* the heat. The battery voltage drives electrons through the resistance of the filament and does work. The result of the work here is to produce heat and light.

When you visited the radio broadcast transmitting station, you both saw and heard a motor begin to turn and then whirl steadily. There, power was developed when the current flowed through the coils of the motor and produced both motion and heat.

How is power calculated? Power in an electrical circuit is easily found by a formula. Power is the result of pressure exerted on electrons and their rate of flow (voltage times current). Power is expressed in watts; 1 watt is equal to 1 ampere times 1 volt. Here is the formula

$$\text{Power} = \text{voltage} \times \text{current}$$

Or you can write it in symbols as

$$P = E \times I$$

where P = power in watts
E = volts
I = amperes

Examples:

1. How many watts of power are used by a lamp that operates on a 100-volt circuit and that draws 1 ampere of current?

$$P = E \times I$$

where E = 100 volts, circuit voltage
I = 1 ampere, circuit current

$$P = 100 \times 1$$
$$= 100 \text{ watts}$$

2. How much power is drawn from the A battery by a 1H4G tube that operates at 2 volts and 0.06 ampere?

$$P = E \times I$$

where E = 2 volts, filament voltage
I = 0.06 ampere filament current

$$P = 2 \times 0.06$$
$$= 0.12 \text{ watt}$$

There are other ways to write the power formula. Your instructor will show you how they can be worked out from Ohm's law, $E = I \times R$, and the simple power formula, $P = E \times I$. Here is a widely used form

$$P = I^2 R$$

When written this way, the formula is handy for use in studying radio circuits. For example, you can easily calculate the amount of power developed as heat in a resistor of 50,000 ohms when a plate current of 5 milliamperes flows through it. (Amperes must be used in these formulas instead of milliamperes. Five milliamperes is $\frac{5}{1000}$ ampere, or 0.005 ampere. Multiply milliamperes by 1000 to get amperes.)

$$P = I^2 R$$

where I = 0.005 ampere (5 milliamperes)
R = 50,000 ohms

$$
\begin{aligned}
P &= (0.005)^2 \times 50{,}000 \\
&= 0.000025 \times 50{,}000 \\
&= 1.25 \text{ watts}
\end{aligned}
$$

These formulas apply only to circuits in which there are direct currents and voltages. Even in alternating current and radio circuits, however, the idea of power represented by the formulas is useful, though the formula isn't strictly correct in all such cases.

Power is used and controlled in a radio circuit. Power in a radio or audio tube circuit comes from the B battery. This power is controlled by the electrons on the grid, which cause it to act like a valve, shutting off or turning on this power. The power is used in the coupling device, which passes it on to the next stage of the circuit, until, in a receiving set, the power finally is converted by the loudspeaker into sound.

A signal set up in the antenna by a passing radio wave is a very weak alternating current. It is measured in microvolts and microamperes (*micro* means one millionth). There is very little power in the antenna. Yet, by using this weak power to drive electrons on and off the grid of a radio-frequency amplifier tube, you start a train of events which finally gives you very loud sounds from your loudspeaker. Let us follow this process briefly.

The weak current in the antenna circuit induces a surging, or oscillating, current in the tuned secondary circuit. Oscillating surges in the secondary circuit drive electrons on or pull them off the amplifier grid.

In both the antenna circuit and the tuned amplifier circuit, there is very little power. But there is much power available from the B battery or the power supply attached to the amplifier plate circuit.

It is the job of the tube to control this power. You already know how the electrons on the grid of the tube control the strength of the plate current. You can easily see that a change of a few microvolts on the grid of a radio-frequency amplifier can control the flow of a plate current of 2 milliamperes, thousands of times stronger than the surges on the grid or the antenna current. (Small voltage changes on the grid produce relatively large changes in the strength of the plate current.)

The plate current now flows through a coupling transformer, and the current changes in its primary induce a voltage in its

secondary. This voltage forces electrons on or pulls them off the grid of the next tube.

Because each tube amplifies, the voltage changes on each succeeding amplifier grid are stronger and control more power in the plate circuit. Finally, a strong voltage on the audio-frequency power-amplifier grid controls a plate current of about 30 milliamperes in a pentode power tube, or about 60 milliamperes in a beam power tube. This powerful current now can produce the motion in the speaker necessary to make a great volume of sound.

The coupling circuit's job is to transfer as much power as possible from the plate circuit of one tube to the grid circuit of the next. It will do so only under certain conditions.

Rule. Maximum power is transferred from one circuit to the next when the plate impedance of the tube is the same as the impedance of its load. This would demand that a tube with a plate impedance of 12,000 ohms be connected to a coupling transformer or resistor with impedance of 12,000 ohms. (This is the alternating-current resistance, not the direct-current resistance.)

But there are practical reasons why other than an exact impedance match is used.

What are some practical coupling methods? Two kinds of coupling are used, one for voltage amplification and the other for power amplification. Examples of the use of coupling to produce voltage amplification are the coupling between radio-frequency amplifiers, between a radio-frequency amplifier and a detector, between a detector and an audio amplifier, and between audio amplifiers. Each stage requires almost no current (and, therefore, very little power) from the preceding stage. The audio-frequency power amplifier, however, must sometimes deliver appreciable current; this is why it is called a power amplifier.

What kind of coupling is used between radio-frequency stages? You can purchase antenna coils and interstage coupling coils in matched sets designed for the tubes and radio-frequency-amplifier circuits in which they are to be used. They produce the high impedances necessary in coupling devices used for voltage amplification. This kind of coupling is used between stages of a radio-frequency amplifier because the high-gain tubes have a high-amplification factor and high plate resistance. The radio-frequency coupling transformer is wound on an insulating form. These coils operate at or

near resonance, so that they form a high-impedance load for the tube.

There is a large voltage drop across the high impedance of the coupling-transformer primary. Since this is a step-up transformer, there will be a larger voltage across the secondary and on the grid of the following tube.

How are audio-amplifier stages coupled? Two stages of an audio amplifier are coupled either with an iron-core transformer (see Fig. 327) or with a resistance-condenser combination. Trans-

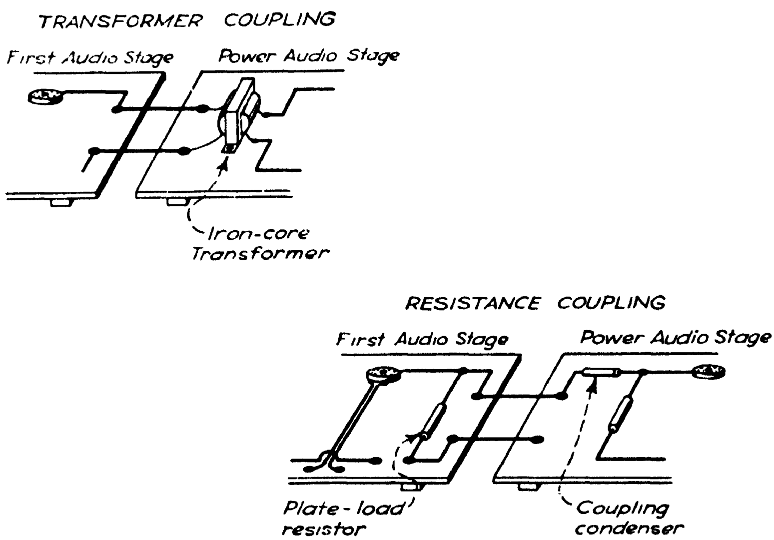


FIG. 327. Audio amplifiers may be coupled together by means of an iron-core transformer or by a resistance-condenser coupling as shown here.

former coupling is generally used with low- or medium-mu tubes. The primary impedance of the transformer is about twice the plate impedance of the tube. This reduces the distortion of the signal that would occur if equal impedances were used. Good power transfer between stages is sacrificed to improve the quality of the music and sound.

The resistance-coupled circuit is ordinarily used with high-mu tubes. The plate-load resistor (see Fig. 328) can be several times the plate resistance of the tube. Then the changes in current strength through the plate-load resistor will cause a large voltage drop (*IR* drop), and the voltage on the next tube grid will be

greater than on the first tube. There is relatively little distortion in a well-designed resistance-coupled amplifier.

If the plate load has too high a resistance, it will cut down the plate current too much. Therefore, its resistance must be a com-

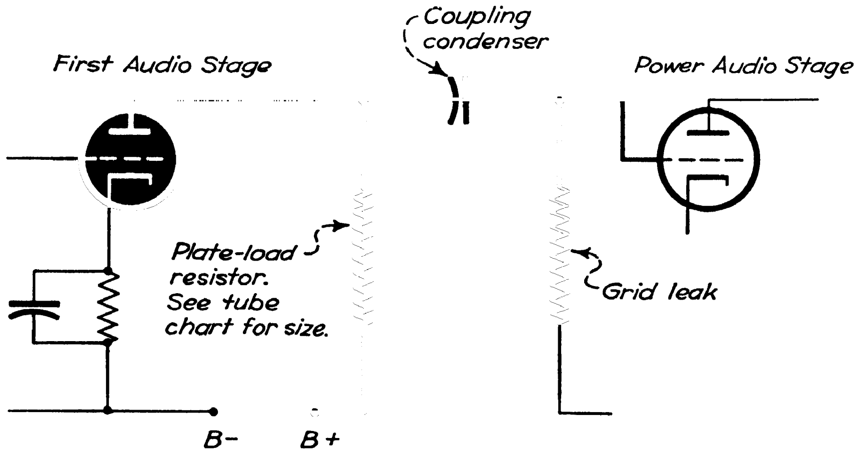


FIG. 328. This is the circuit for resistance coupling between audio-amplifying circuits. It may also be used between detector and an audio amplifier.

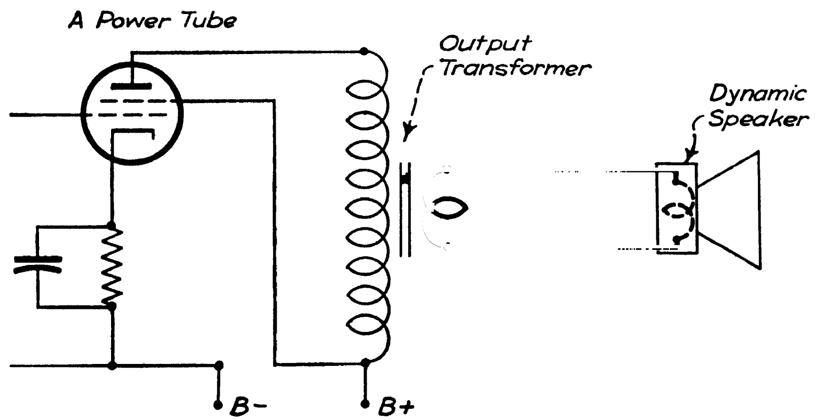


FIG. 329. Coupling circuit used between a power audio amplifier and the voice coil of the speaker. The small *output transformer* must be specially wound to fit the tube and the impedance of the speaker voice coil. Sometimes a universal output transformer is used for experimental work.

promise between a size large enough for good amplification and a size small enough not to cut down the plate current too much.

How are the power tube and the speaker coupled? An output transformer is used to couple the power-amplifier tube to the

speaker (see Fig. 329). The power tube has a low mu and a low plate resistance, so that a relatively large plate current will flow. A low-impedance coupling transformer is used. The transformer's primary impedance has about twice the tube's plate impedance.

The secondary is wound so that it has the same impedance as the voice coil of the speaker. This arrangement gives the best power transfer, with low distortion.

A universal output transformer is often used by experimenters. Such a transformer can be used with many different tubes which have different plate impedances. A universal output transformer has a tapped secondary winding. Each tap is connected to a soldering lug. You move the voice-coil connection from tap to tap to the point where the music is loudest and clearest. At this point you have the best impedance match between transformer and tube and between transformer and voice coil.

PART 7: HOW THE RADIO-FREQUENCY AMPLIFIER IS BUILT

Why is the radio-frequency amplifier used? An audio amplifier can build up the strength of a weak signal from the detector until the sounds from its loudspeaker can be heard for blocks. But there is a practical limit to audio amplification. It is limited by the noise introduced by the tube, by imperfect contacts, and by slight voltage changes. Distortion originating in the tubes or the circuit may also be magnified.

Another way to build up the signal is to amplify it before it reaches the detector. The signal on the antenna may be amplified through several radio-frequency amplifier stages.

The radio-frequency amplifier has considerable *gain,* or ability to increase signal strength. In the process, it has the effect of making the set more sensitive to weak signals. This enables the set to receive signals over greater distances and to receive signals from low-power nearby stations that you were unable to hear before.

What tubes are used for radio-frequency amplifiers? The pentode tube makes an excellent radio-frequency amplifier. The tube used in the circuit you are about to build is a voltage amplifier with large mutual conductance. The tube used for this purpose is the 6J7 or the 6K7.

How to Build and Wire the Set

Mount and wire the parts for the radio-frequency amplifier on a small set board, as shown in Figs. 330 and 331.

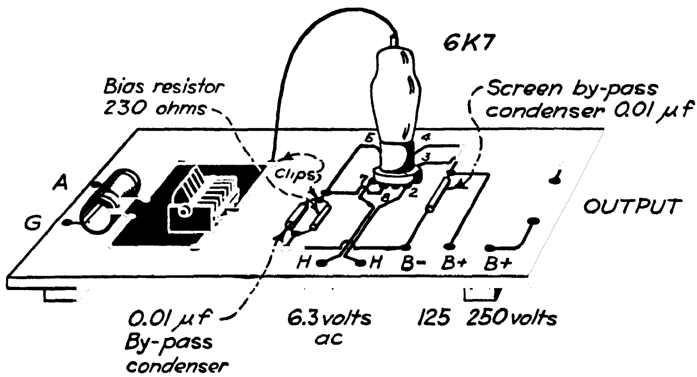


FIG. 330. The board layout for a radio-frequency amplifier.

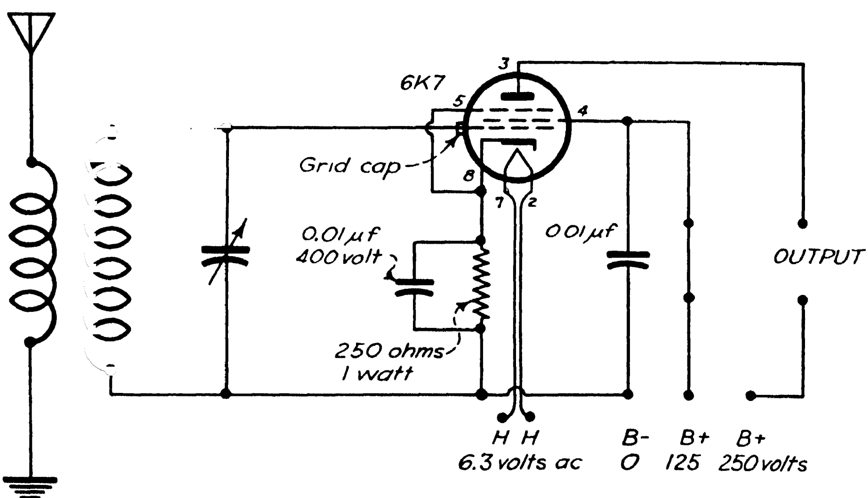


FIG. 331. The circuit diagram for the radio-frequency amplifier.

The coil. Use the same coil that you used in the detector circuits you studied earlier, or a similar one. Here the standard radio-frequency transformer is called the *antenna coil.* Antenna and detector coils can be purchased in matched sets.

The condenser. Use a standard small-sized broadcast-tuning variable condenser.

Clips. Arrange the clips so that you can try different sizes of bias resistors and by-pass condensers.

Wiring. Arrange wiring as shown in Figs. 330 and 331.

How to Operate It

Step 1. Connect together the radio-frequency amplifier, the detector, and the audio-amplifier circuit boards, as shown in Fig. 332.

Step 2. Connect the filament heater from the power supply to all boards. Test these connections as before.

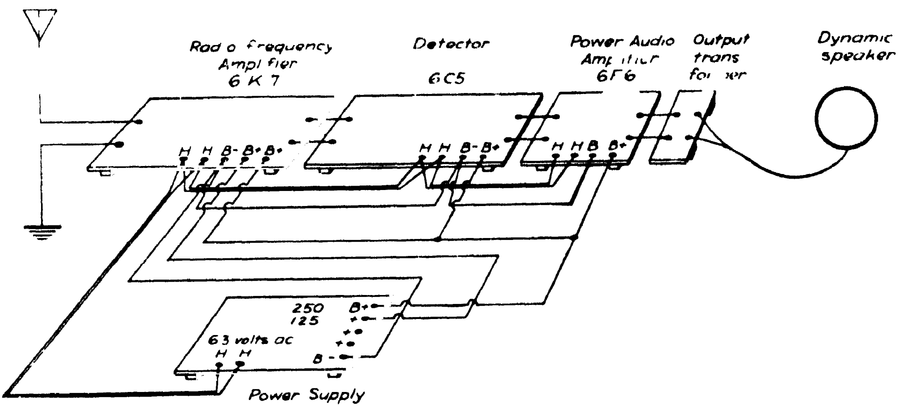


FIG. 332. Connect these three boards together to form a three-tube set.

Step 3. Connect the B-minus and B-plus wires as explained for the audio amplifier.

Step 4. Recheck the circuit before turning on the B power.

Step 5. Tune the radio-frequency amplifier and the detector to bring in a station.

Further Tests to Try

Test 1. Try changing the grid-bias voltage on the radio-frequency amplifier tube. Do this by attaching resistors of different values to the clips in the cathode circuit. Note its effect on the sensitivity of this tube by tuning to the same stations before and after the change. (If this makes the set more sensitive, the signals will be louder.)

Test 2. Try changing the screen voltage on the radio-frequency tube to see its effect on the sensitivity. Use a different voltage tap on the power supply to do this.

Why It Works

You have already studied the audio-frequency amplifier and know how it amplifies. There is no difference between the basic theory of operation of this amplifier and that of the radio-frequency amplifier.

The radio-frequency amplifier is biased so that the zero grid-voltage point falls near the center of the grid curve. A signal on the grid then produces plate-current changes of similar wave shape but of greater amplitude. Audio amplifiers operate over a wide band of frequencies; tuned radio-frequency amplifiers operate over a narrow band of frequencies.

The primary and secondary of the antenna coils and any coupling transformers must be wound on nonmagnetic forms, such as Bakelite or other low-loss materials.

The by-pass condensers are of smaller capacity than in audio-frequency circuits, because the frequencies involved are so very much higher that the same amount of by-passing action is obtained with a small value of capacitance. Otherwise, the circuit is similar to that of the audio amplifier.

PART 8: HOW TO BUILD A SINGLE-CONTROL RECEIVER

How is tracking accomplished? After you have studied the different circuits in this chapter, you will enjoy assembling them into a practical receiver. You will now do this and get the single-control receiver described here. To it you can add several improvements over the basic circuits given earlier in this chapter. We will describe only three improvements: gang tuning, the volume-control circuit, and the power detector.

This set is made up of the same unit circuits that you have already studied. They may simply be set together and tried out, rebuilt on a larger board with a three-gang variable-tuning condenser, or built on a metal chassis.

A de luxe receiver made to receive distant and weak stations on long and short waves has many tubes. Such a set may have two or more radio-frequency stages and a detector that must be tuned. If this fine receiving set were built like the experimental sets you have been using, it would be difficult to tune and so inconvenient that few could handle it.

The problem of tuning so many circuits was solved by set designers, who mounted all tuning condensers on the same shaft, so that all circuits were tuned at the same time by turning a single knob. In one early set, three separate condensers were used with a wheel on the front of each. A narrow metal belt connected all three together. When the knob turned one condenser, the other two followed.

The need for tracking became apparent when slight differences in coils, condensers, and their wiring kept the separate circuits from tuning to the same frequency when the condenser control was

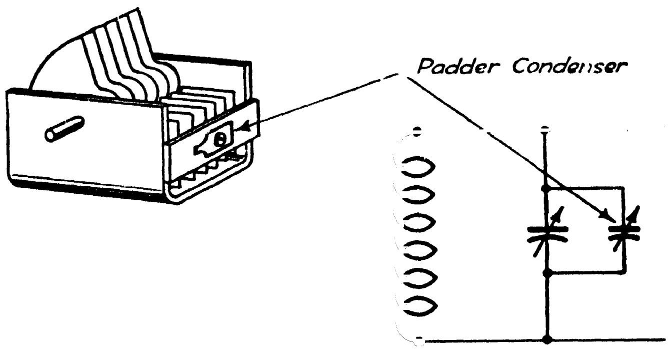


FIG. 333. The small padder condenser is connected in parallel with the main tuning condenser to align the different tuning circuits so that they will track.

turned. Although this set was far more convenient to operate than was the one with three separate controls to adjust, it was less sensitive. The three circuits were not all tuned at the same time. *Tracking*, which is the process of getting all circuits to track, or tune, together, was obtained in this early set by slipping the belt enough so that the three circuits tuned the same at any point on the dial. With care in circuit adjustment, fairly good tracking could be accomplished.

Tracking adjustment is now carried out by means of a small condenser connected in parallel with the main tuning condenser (see Fig. 333). These small condensers are adjusted by the serviceman who aligns your set. They are usually called *padders*.

How to build and wire the set. Mount a small three-gang condenser on a large set board. This will give you a two-stage radio-frequency amplifier and a detector on one board.

How to operate it. Connect a pentode power amplifier to this set. Connect a signal generator and a speaker to the set. Wire the set to the power supply, and you are ready to align it.

Aligning procedure. The broadcast band of frequencies over which this set will tune is from 550 to 1700 kilocycles. To align your receiver, you will need a signal generator such as is used by radio servicemen. The *signal generator* is simply a stable oscillator which acts as a weak transmitter. It provides you with a signal

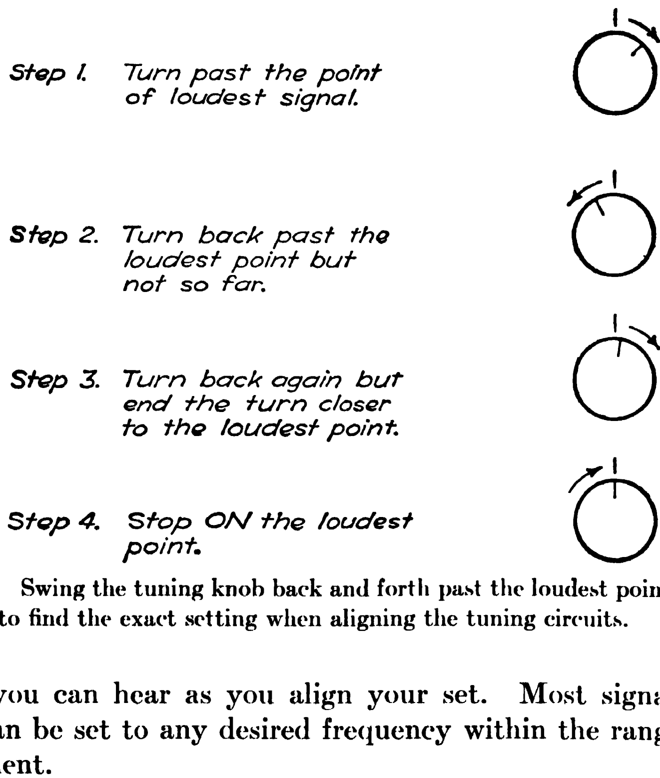


FIG. 334. Swing the tuning knob back and forth past the loudest point of signal strength to find the exact setting when aligning the tuning circuits.

which you can hear as you align your set. Most signal generators can be set to any desired frequency within the range of the instrument.

Step 1. Set the signal generator to a frequency of 1000 kilocycles. Turn on the receiver and the signal generator.

Step 2. Tune the receiver until you hear the steady tone of the signal generator. Turn the volume control, or *attenuator*, of the signal generator until the tone is weak.

Step 3. Adjust the padder condenser on the detector tuning condenser. Turn it to the right past the loudest point, and then turn it to the left past the loudest point (see Fig. 334). Continue

making each swing shorter until you are exactly on the point where the tone is loudest.

Step 4. Now align the two radio-frequency stages in a similar manner.

Step 5. Remove the signal generator, and connect the antenna and ground to the set. Your set will now tune accurately and will operate well.

Why it works. The station will be heard loudest and clearest when each radio-frequency amplifier stage and the detector are tuned exactly to resonance with the carrier frequency of that station. If any of these circuits is tuned off the station even a little, both the strength of current flowing in the tuning circuit and the loudness of the music are reduced.

When you tune each stage individually, it is easy to adjust each circuit exactly "on the nose." Since you cannot do this with a single-control set, you attach a padder condenser in parallel across each tuning condenser. Then, when you adjust the padder condenser, you add more or less capacity to make up for any difference in the mechanical or electrical size of the circuit. When the padders are correctly adjusted, the circuits will tune as closely together as is practically possible.

Questions

1. What is the source of power in a radio circuit?
2. Why must we watch impedances in coupling one stage to another?
3. Why is it important to calculate the power in a radio circuit?
4. Describe how to align a set which has single-control tuning.

PART 9: THE POWER DETECTOR

You now have all the essential parts of the modern receiver in your single-control set. But because there are two stages of radio-frequency amplification, the signal will be too strong for the grid-condenser grid-leak detector.

The *power detector*, sometimes called a *plate detector*, is better suited for your new circuit, because it will handle stronger signals. The grid-leak detector is fine for the beginner. It is simple, easy to operate, and sensitive to weak signals. But powerful signals from nearby broadcasting stations may block the grid-leak detector and stop the set's playing. The power detector is preferred when strong nearby stations are to be received. Several stages of

radio-frequency amplification are used ahead of this detector. It supplies strong signals to the audio amplifier.

How to build and wire the set. Mount this circuit on a large set board. Arrange the parts as shown in Fig. 335. Wire the set as shown in the schematic diagram, Fig. 336. Use a standard broadcast-range coil and condenser for the tuning unit. Note that

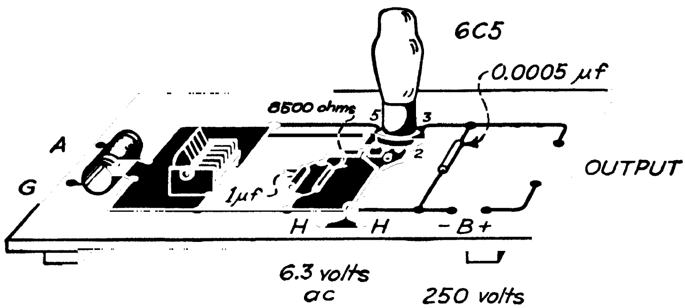


FIG. 335. The layout of the *power detector.*

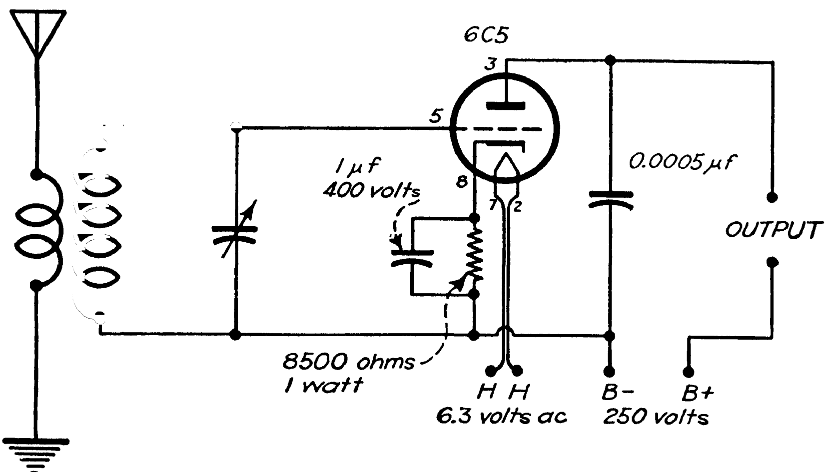


FIG. 336. The schematic diagram of the *power detector.*

no grid condenser and leak are used. Instead, a bias resistor and condenser are wired into the cathode lead.

How to operate it. Set up the detector board by connecting the antenna and ground and phones. Compare its operation with that of the grid-leak detector.

Next, connect the detector board to a radio-frequency amplifier and an audio amplifier, as shown in Fig. 337.

Follow the procedure of wiring that you learned earlier:

Step 1. Wire heaters and test them.

Step 2. Run all B-minus wires.

Step 3. Run all B-plus wires.

Step 4. Make a careful check.

Step 5. Operate the set.

Note that this detector uses high plate voltage with 250 volts on the plate. Use a 1-watt bias resistor of 8500 ohms.

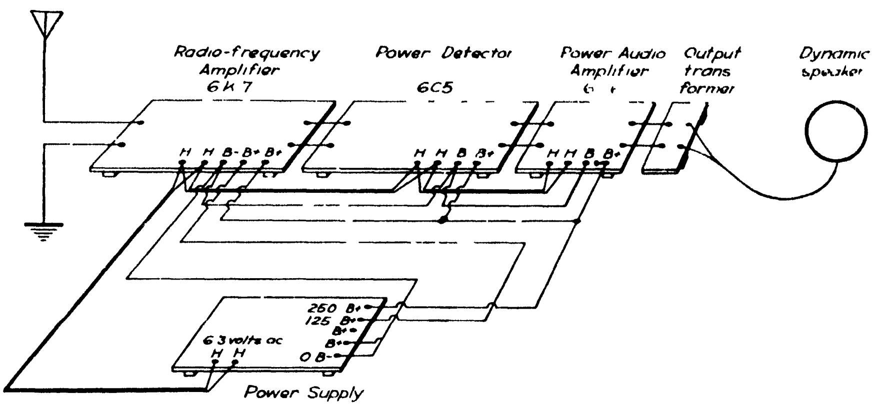


FIG. 337. Connect the power detector to a radio-frequency amplifier and an audio-frequency amplifier to make a three-tube set. You can get greater distance by adding a second radio-frequency amplifier ahead of the first.

Why it works. The power detector, unlike the grid-condenser grid-leak detector, causes the plate current to rise more when the signal is positive than it drops when the signal is negative. Let us see how this occurs.

The high plate voltage (250 volts) draws much more current (8 milliamperes) through the tube than did the 45 volts used on the grid-leak detector. Examine the grid curve in Fig. 338. This curve shows several facts useful to your study of the power detector: First, that with the higher plate voltage, more plate current flows through the tube than with the grid-leak detector, which raises the whole curve; second, that since the plate voltage is higher, the grid has to be made more negative to reach cutoff, the point where no plate current flows. The cutoff point is to the left of the zero line for the grid with no bias.

Bias is needed for detection. To use this tube as a detector, it must be biased enough to move the grid zero line over to the lower knee of the curve. (The bend of the curve is called the *knee*.) The new zero-signal position of the grid is now 16 volts to the left of the zero position with no grid bias (see Fig. 338).

The plate current, with no signal on the grid and no bias, is 8 milliamperes. But when the tube is biased, much less plate current flows, only about 2 milliamperes. The detector tube must cut off part or all of the negative half of each radio-frequency surge. It must act as a half-wave rectifier. A 17-volt negative bias is necessary for power detection.

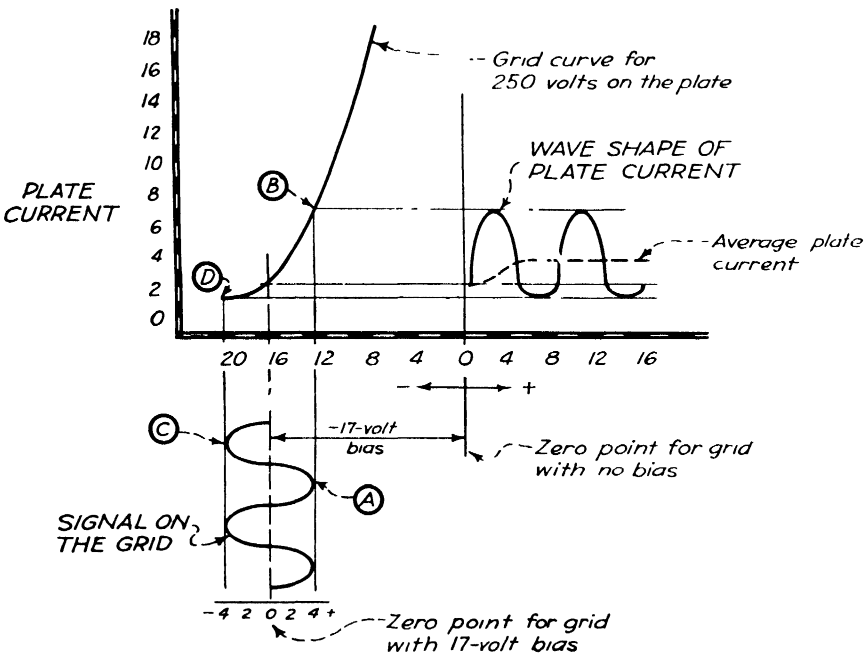


FIG. 338. The grid curve shows how the power detector operates. This is an engineering type diagram.

How does the tube detect? Now watch what takes place when a 4-volt signal reaches the grid. On the positive part of the signal, the grid becomes *less negative* by 4 volts $(-17 + 4 = -13)$. Thus it is actually 13 volts negative. Then the signal makes the grid *more negative* $[-17 + (-4) = -21]$, and so it becomes 21

volts negative. You can see this on the grid curve. The 4-volt signal on the grid is shown below the curve on the grid zero line.

Draw a line up from the signal wave on the grid line (point *A*) to touch the grid curve at *B*. This shows that when the 4-volt positive signal reaches the grid, it makes the grid less negative, and the plate current becomes about 5 milliamperes stronger.

Now, when the grid is made 4 volts more negative by the negative part of the signal wave at *C*, the grid becomes 21 volts negative. This makes the plate current weaker (see point *D* on the grid curve).

As you will recall from your study of the grid-leak detector, the grid curve shows that the grid has less control of the plate current when few electrons flow through the tube than when many electrons flow through the tube. This is shown by the bend at the lower end of the curve. Therefore, when the negative part of the signal makes the grid more negative, the plate current becomes weaker. But note that a 4-volt positive signal increased the plate current about 5 milliamperes, while a 4-volt negative signal only decreased it by $\frac{1}{2}$ milliampere. The sine wave of the signal on the grid makes a plate-current wave that looks somewhat like the wave shape of the rectifier tube's plate current in the power-supply circuit (see Fig. 266 in Chapter 14). The effect of the detector is similar to rectification. But unlike rectification, the voltage on the grid is not rectified; it only produces that effect on the plate current. This uneven effect that the signal on the grid has on the plate current produces detection.

How are the radio-frequency surges regrouped? Examine the diagram in Fig. 339. It shows that the radio-frequency surges on the grid produce radio-frequency surges of the plate current with a distorted wave shape. Much of the lower part of the plate-current wave is cut off. (This gives the plate-current wave the appearance of a rectified wave.)

When these plate-current surges reach the plate by-pass condenser and experience the choking action of the resistance or the transformer used for coupling the power detector to the audio amplifier, the result is a blend of the many radio-frequency surges into fewer audio surges. The action is similar to that of the crystal detector, in which the one-way flow of current, even at radio frequency, easily operates the earphones. Here, also, the plate cur-

rent, stronger in one direction than the other, produces sound in the earphones. You read about this in Chapters 9 and 12.

Power detection is the same as grid-leak detection, except that the grid bias is obtained from the voltage drop across the bias resistor instead of from the grid condenser and grid leak.

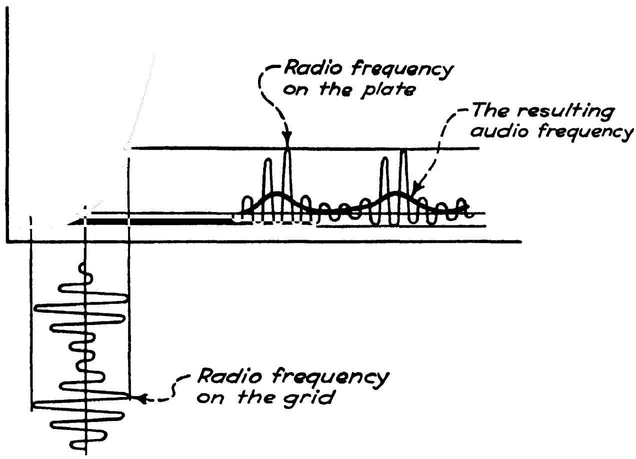


FIG. 339. Note how the radio-frequency wave on the grid is distorted as it appears in the plate-circuit wave. The lower part of the wave is much reduced. This makes possible detection.

Questions

1. What does the power detector use in place of the grid leak and grid condenser?
2. What would be the disadvantage in a power detector of putting a positive bias on the grid and shifting the operation over to the upper knee of the curve?
3. Would the power detector operate if you adjusted the bias so that it operated on the straight-line position of the curve? Explain.

PART 10: VOLUME-CONTROL CIRCUITS AND HOW THEY OPERATE

Many of the stations you pick up as you tune across the dial are uncomfortably loud. There are several ways in which you can control the volume of the program.

You might control the sound volume by changing the filament or plate voltage. This method was used in early sets, but it is a poor method and is no longer used. Two commonly used volume-control methods reduce volume either by increasing the negative grid bias on the radio-frequency amplifier or by cutting down the input to the first audio-amplifier tube.

How to Build and Wire the Set. Install the circuits described here in the sets you have already built.

Grid-bias Volume Control. This circuit is shown in Fig. 340. A 50,000-ohm volume-control resistor is wired in series with the grid-bias resistor. Note that the by-pass condenser now is shunted across both of the resistors.

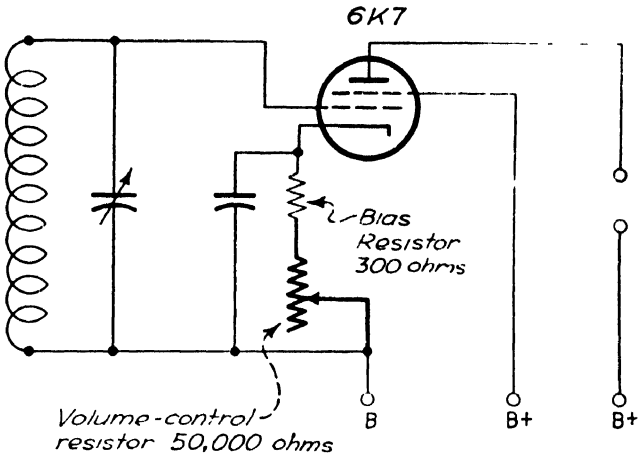


FIG. 340. How the volume-control resistor is connected in the radio-frequency amplifier circuit.

Audio-circuit Volume Control. This type of volume control is wired as shown in Fig. 341. Here a 50,000-ohm volume-control potentiometer is connected across the secondary of the audio transformer used to couple the detector to the first audio amplifier.

Note that the grid is connected to the moving arm and the cathode is connected to the lower end of the potentiometer volume control.

How it works. *Grid-bias Control.* This circuit simply changes the voltage drop across the bias resistor, which now consists of the regular resistor plus the volume control. As the contact moves on the volume-control potentiometer, it changes the total resistance in the circuit. This changes the voltage, or *IR*, drop across the resistor. This *IR* drop produces the grid bias.

When the bias increases, the grid becomes more negative and the music becomes weaker. You can make the grid so negative that the tube reaches cutoff and no plate current flows.

When the bias is decreased, the signal becomes stronger.

Audio-circuit Control. This circuit operates on a different principle. It acts like the voltage-divider bleeder you studied in Chapter 14, "Power Supplies." When you move the pointer to *Y* (see Fig. 341), there is no signal on the grid. But as you move the pointer toward *X*, the signal increases, because there is a voltage drop between *X* and *Y*. This drop is greater as you move the pointer further toward *X*, where you get the loudest music.

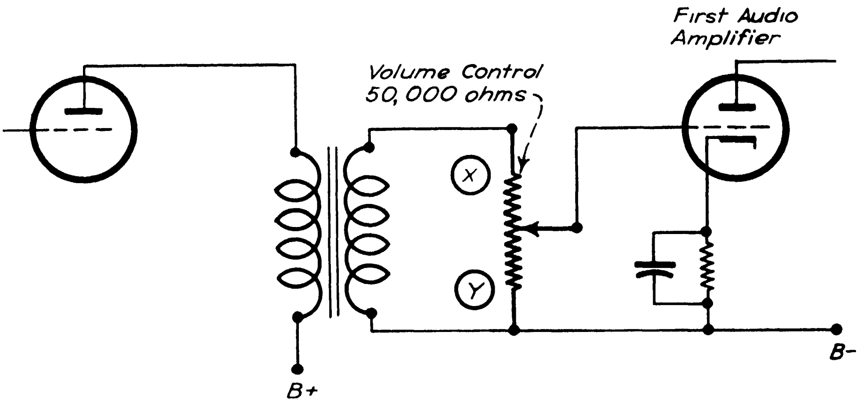


FIG. 341. How the volume-control resistor is connected in the audio-amplifier circuit.

Technical Terms

attenuator—A resistor in the output circuit of the signal generator used to control its output voltage.

distortion—Fuzzy or unnatural rendition of music or the voice. Distortion may be produced by incorrect grid bias.

gain Increase in signal strength.

grid bias -The steady negative voltage on the grid.

micro —One millionth.

padder - A variable condenser of low capacity connected in parallel across the tuning condenser. The padder, usually a mica dielectric compression type of condenser, is used to make small adjustments to align several tuning circuits for tracking.

signal generator—An accurate, stable radio-frequency amplifier used to align the tuning circuits of a receiving set.

tracking—Correctly adjusting tuning circuits so that they will tune together on track across the entire tuning dial.

watts—The unit of power. Watts equal volts times amperes.

CHAPTER 17

THE SUPERHETERODYNE RECEIVER

When you review the work you have been doing on receiving circuits, you will find that the one-tube receiver was an improvement over the crystal detector. But this was only one of many improvements. Another improvement was the audio amplifier, which made the music louder. The receiving set was then made more sensitive by adding the radio-frequency amplifier, which brought in distant stations you had been unable to hear before. Its selectivity was improved by adding tuned circuits in the detector and the radio-frequency amplifier stages. You could then tune more sharply and cut out interfering stations more easily. Tuning was simplified by ganging the tuning condensers, so that the whole set could be tuned by a single knob. The result of making such improvements in commercial sets was the popular five- or six-tube tuned-radio-frequency receiver, a popular, rugged, and inexpensive set.

However, the tuned radio-frequency set had several faults. The radio-frequency amplifier and the detector circuits were inefficient, because they were designed to tune over a wide band of frequencies. Furthermore, there was a practical limit to the number of audio-amplifier stages that could be used, because tube and circuit noises were amplified into objectionable background noise.

The superheterodyne circuit overcomes these difficulties and adds a new feature, namely, a radio-frequency amplifier that operates on a band of frequencies about 10,000 cycles (10 kilocycles) wide. This amplifier is much more efficient than the usual radio-frequency amplifiers that must operate at reduced efficiency over the band of frequencies used by most broadcasting stations (500 to 1500 kilocycles, a band 1000 kilocycles wide). The superheterodyne receiver is so efficient that it is widely used in broadcasting and communication work.

You will learn the following things in this chapter:

Part 1: What the Superheterodyne Principle Is
Part 2: How to Line Up the Intermediate-frequency Transformers
Part 3: How the Diode Detector Operates
Part 4: How Automatic Volume Control Works

PART 1: WHAT THE SUPERHETERODYNE PRINCIPLE IS

What are the new units in the superheterodyne receiver? Examine the block diagram in Fig. 342. Note the new radio-frequency amplifier stage that follows the new *mixer*, or *first detector*, stage. It is called the *intermediate-frequency* (*i-f*) *amplifier*. This is the *fixed-tuned* amplifier that makes the superhetero-

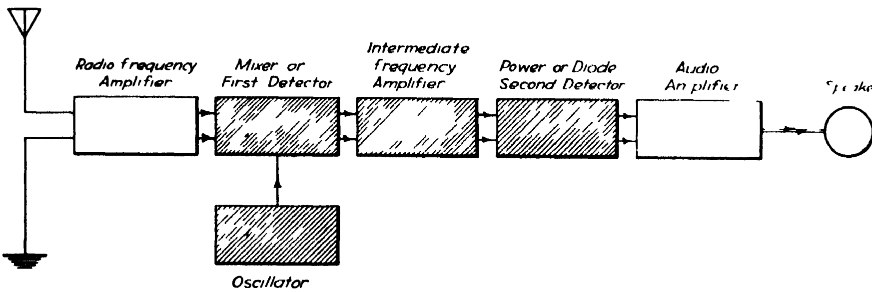


FIG. 342. Block diagram of the superheterodyne receiver. Note the new units in this receiver shown in the shaded blocks. They are the *mixer*, the *oscillator*, the *intermediate-frequency amplifier*, and the *power*, or *diode, detector*.

dyne so efficient. The intermediate-frequency circuits will allow only a signal of 455 kilocycles to pass through it and will kill all other signals. But when you want to hear a station that operates on a frequency of 680 kilocycles, let us say, you need some special circuit to change its frequency, so that its signal will go through the sharply tuned 455-kilocycle intermediate-frequency amplifier.

The new mixer stage and the oscillator stage direct the 680-kilocycle signal, or any other frequency of signal you wish to hear, through the fixed-frequency intermediate-frequency amplifier. An ingenious method for doing this was worked out by E. H. Armstrong, the inventor of the superheterodyne. He found a simple way of using the beat-note principle (explained later in this chapter) to convert these different station frequencies to 455 kilocycles. He fed the signal from an oscillator, a new circuit shown in the block diagram, Fig. 342, into the first detector, where it combined,

or mixed, with the incoming carrier wave from the station to which his receiver was tuned. This produced a *beat frequency*.

By making the beat frequency come out as the frequency to which the highly efficient intermediate-frequency amplifier was tuned, signals could be received. This is explained in detail later.

Examine the new circuit units. The new units in this circuit are represented by shaded blocks in Fig. 342. Examine each new circuit.

The mixer, or first detector, is the first shaded block. This circuit combines, or mixes, the incoming signal with a signal from the oscillator, so that the resulting frequency will be 455 kilocycles. This is explained in "How It Works" later in the chapter.

The mixer is a detector with connections to the oscillator and the radio-frequency amplifier. You will study only one of the several ways to connect the oscillator to the mixer.

The Oscillator. This may be the same circuit as that used in transmitters (see Chapter 20, "Power Oscillators and Amplifier Circuits"). The oscillator sets up a signal that is fed into the mixer, as shown in Fig. 342.

The Intermediate-frequency Unit. This is simply a fixed-tuned radio-frequency amplifier. It may include a volume control in series with the bias resistor.

Examine an intermediate-frequency transformer. Remove the cover from an intermediate-frequency transformer unit, and examine the coils and tuning condensers. Note that the coils are lattice-wound. The compression type of condenser connected across each coil (see Fig. 343) is tuned by turning the screw on it. Note that the coils are loosely coupled to make tuning sharper.

What does the second detector do? The radio-frequency amplifier, the mixer, the oscillator, and the intermediate-frequency amplifier all operate at radio frequencies. The frequency of the radio-frequency amplifier is the carrier frequency of the station to which you are tuned. This is a *radio frequency*. The *oscillator frequency* is a few hundred kilocycles below the station's carrier frequency. The *intermediate frequency*, 455 kilocycles, is also a radio frequency, and so you will need a detector circuit to regroup the radio-frequency surges from the 455-kilocycle intermediate-frequency amplifier and produce sound in the earphones or speaker.

For this purpose, you may use any detector circuit that you

have studied. But since the superheterodyne receiver has the radio-frequency amplifier and the intermediate-frequency amplifier to build up the signal from the antenna, either a power detec-

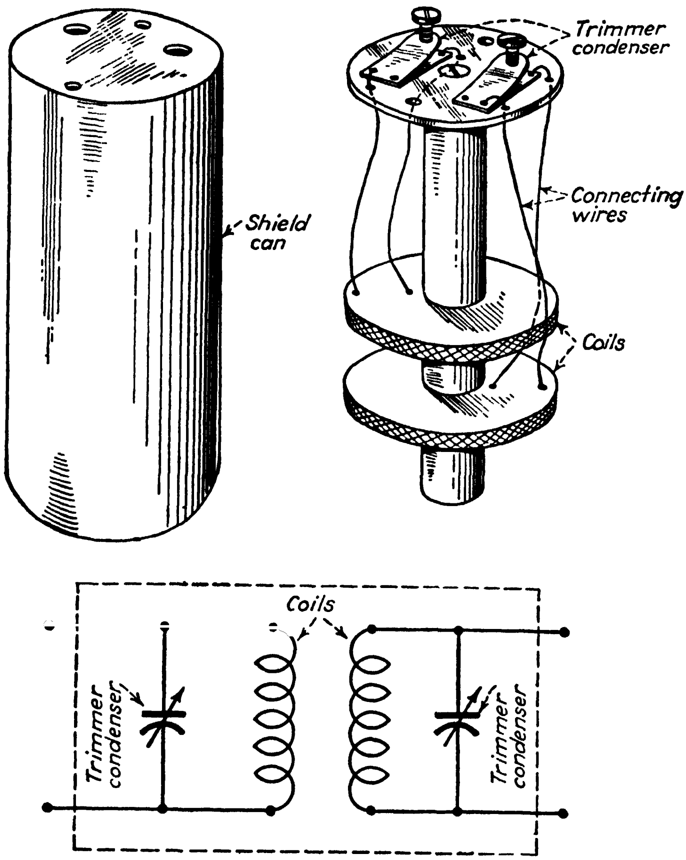


FIG. 343. This shows the intermediate-frequency transformer unit. Note the two lattice-wound coils, the loose coupling between them, and the two compression-type tuning condensers on top of the coils.

tor or a diode detector should be used. A grid-condenser grid-leak detector works poorly on such strong signals.

What are the advantages of the diode detector? As you will recall from earlier chapters (Chapters 9 and 11), you have tried the two-element tube as a detector. This was the tube that Fleming tried to use on Marconi's early equipment in England.

His experiments proved this tube to be commercially impractical because it works well only on strong signals. However, now that we have amplifiers to build up the strength of the signal, we can use the diode tube as a detector. The quality of music is good because the diode detector produces little distortion. The diode detector has another advantage: No B battery is required in its circuit.

Examine the diode circuit. In Figure 344 the diode-detector circuit is shown. Note that the tuner part of the circuit is the same as the one used with the detector circuits with which you have worked. Note that, unlike the triode tube, it has no B

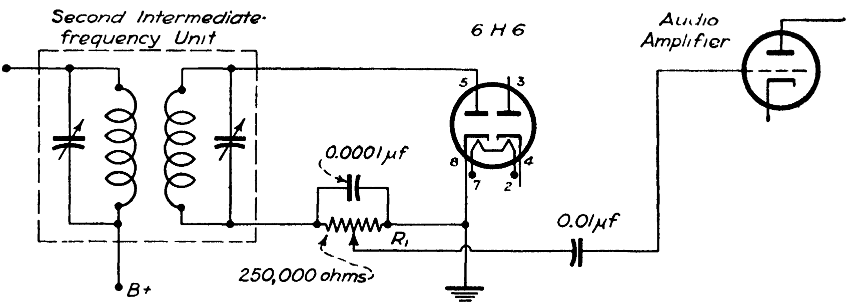


FIG. 344. Circuit diagram of the diode detector. Note that the tuning circuit for the diode is the secondary of the second intermediate-frequency unit.

battery. The diode circuit is similar to the rectifier in the power-supply circuit, except that it is a half-wave rectifier. Its operation is explained later in this chapter in "Why It Works." Note the unusual way in which surges are taken off across the resistor R_1. A part of the voltage drop across R_1 is used to drive the audio-amplifier tube.

How to Build and Wire the Set

What is the mixer unit? The mixer is a radio-frequency amplifier. It is sometimes called the *first detector*. Use the circuit board you built when you studied the last chapter (see Figs. 330 and 331). Add a connector terminal at the point marked *X*, as shown in Fig. 345.

Use a 6J7 tube for the mixer circuit. It is a voltage-amplifier tube with good gain, which you will connect in such a way that it will work as a detector. You may also use any of the following tubes: 24A, 57, or 77.

Build and wire the oscillator. This is the Hartley circuit that has long been a favorite because of its simplicity and the ease with which it can be made to oscillate. You will use a 6C5 tube in this

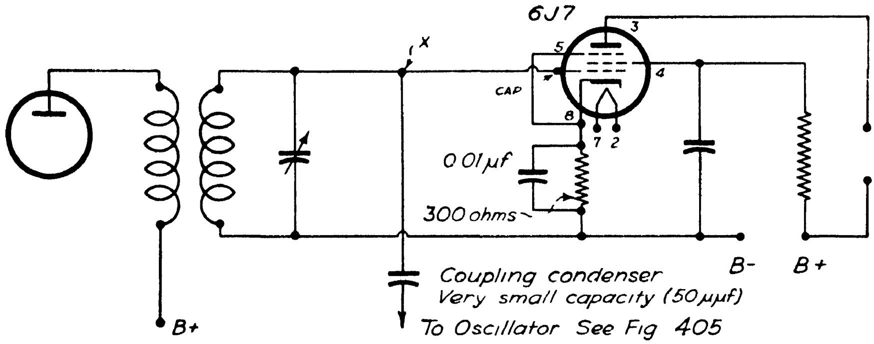


Fig. 345. Mixer circuit. Note the wire connecting the oscillator and the mixer grid. While there are other ways of coupling the oscillator to the mixer, this is a simple and easy type of coupling to use and to operate.

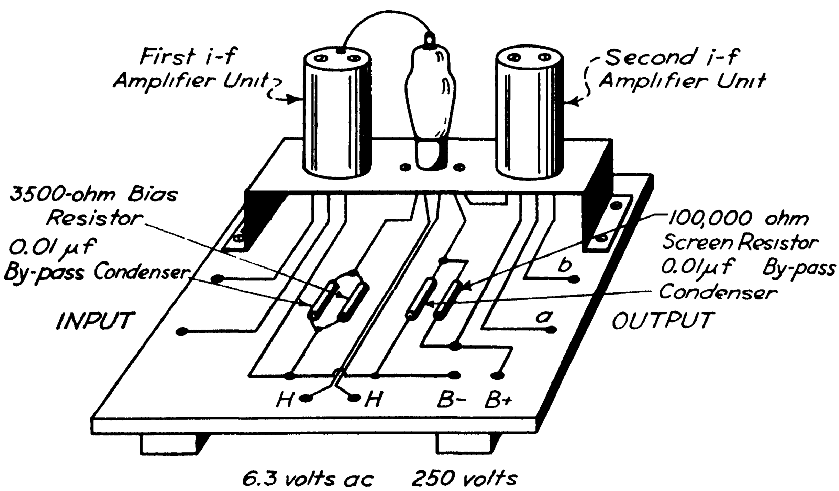


Fig. 346. Board layout for the intermediate-frequency amplifier. By mounting the intermediate-frequency units and the tube on the raised wood or metal shelf, the wiring can be kept in plain view.

circuit. You will study oscillator circuits in detail in Chapter 20, "Power Oscillators and Amplifier Circuits." The instructions for building and wiring the circuit are given in Chapter 20.

Build and wire the intermediate-frequency amplifier. Mount the parts on the small set board, as shown in Fig. 346. Set the intermediate-frequency transformers and their shield cans on a

raised shelf at the back of the circuit board. They are then easy to wire, and the wiring can easily be seen. Make the shelf of metal or of ⅛-inch pressed wood.

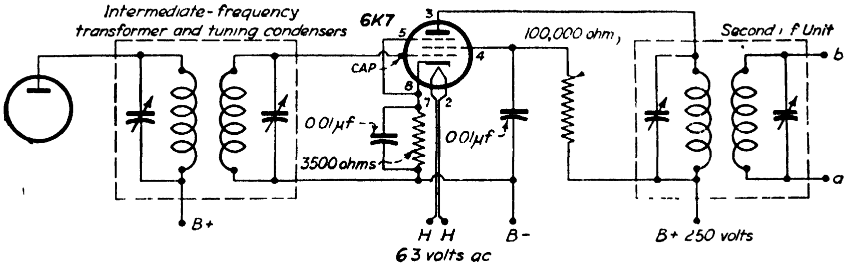


FIG. 347. The intermediate-frequency amplifier. This circuit is a radio-frequency amplifier with its tuned circuits enclosed in shield cans. Sometimes a volume-control resistor is added in series with the bias resistor.

Use a 6K7G, a 78, or a 58 tube for this circuit. The 6K7G is a super-control amplifier tube which will not block on loud signals.

Wire this circuit as shown in Fig. 347.

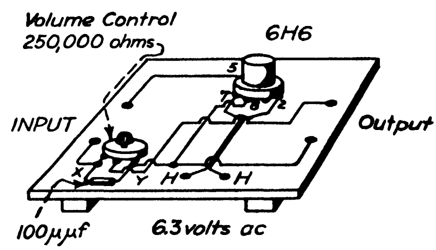


FIG. 348. Board layout for the diode detector. There is no B battery on this unit.

Build and wire the second detector. The second detector can be the power detector you studied in the last chapter, or it can be the diode detector. We shall describe the latter, which you have not yet used.

Build this detector on a small set board. Its tuning circuit is the secondary coil and condenser of the second intermediate-frequency transformer.

Lay out the parts as shown in Fig. 348, and wire the circuit as shown in Fig. 349.

You can use several different types of tubes as diode detectors. For this circuit you can use one side of the 6H6, a duodiode tube, or connect the grid and plate of the 6C5 together, or use one of the diode sections of the 6Q7 or 6R7.

How to Hook Up the Superheterodyne Receiver

Step 1. Connect the different units together as shown in the wiring diagram, Fig. 350.

Step 2. Attach wires from the power supply to the different heater connections, and test the circuit.

Step 3. Connect wires to the B-minus posts on the set boards and to the power supply. Connect the B-minus to ground.

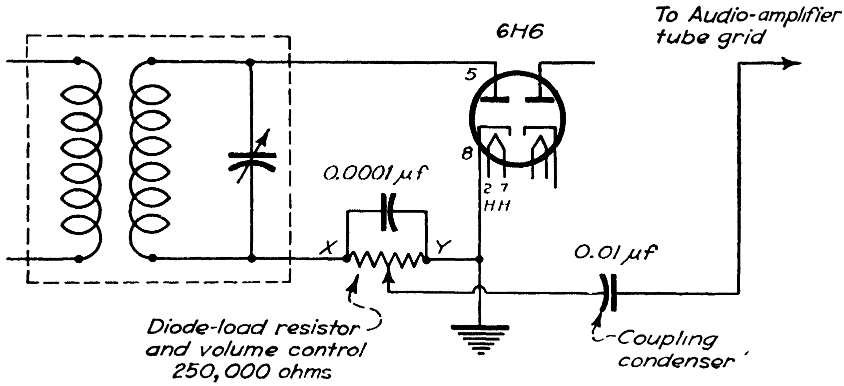


FIG. 349. This is the schematic circuit for the diode detector. Note that only one half of the diode is used in this circuit.

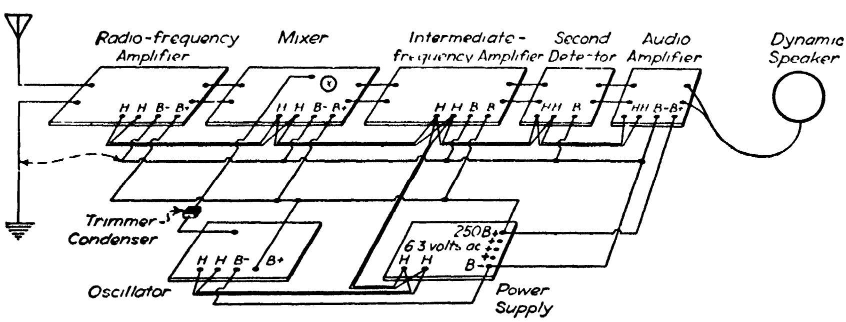


FIG. 350. Connect the units of the superheterodyne receiver together as shown in this diagram. The coupling condenser between the oscillator and the mixer may be a trimmer condenser or merely two insulated wires twisted together. Try connecting B minus to ground. Note any effect it may have on music quality.

Step 4. Connect wires to the B-plus taps on all boards. Check the wiring. Then have the instructor check it before turning on the power.

You are now ready to line up the intermediate-frequency amplifier. This amplifier must be aligned before the set will play.

Questions

1. What type of winding is used on the intermediate-frequency transformers? Why?

2. What type of condenser is used? Why?
3. How is sharp tuning provided for in the coils?
4. What is a diode detector? How does it differ from a triode?
5. Would a superheterodyne set work if you used some other intermediate frequency than 455 kilocycles?

PART 2: HOW TO LINE UP THE INTERMEDIATE-FREQUENCY TRANSFORMERS

When you align the intermediate-frequency transformers, you tune them accurately to the frequency for which they were designed, often 455 kilocycles. The value is usually printed on the shield cans. Use a signal generator of the type employed by radio servicemen to put out a radio-frequency signal for lining up the set. The signal generator is a small oscillator that generates a steady radio-frequency signal, which is modulated so that you can hear a tone in the earphones as you align the circuits of your receiver.

How to line up the intermediate-frequency-amplifier units

Step 1. Turn on the power supply to heat the tube filaments and to supply B voltage.

Step 2. Disconnect the wire from the grid of the intermediate-frequency amplifier tube. (Attach the ground, or B-minus lead, from the signal generator to the B-minus, or ground, of the receiver. This is generally the shield braid on the lead from the output of the signal generator.) Attach the other lead from the signal generator to the grid of the intermediate-frequency tube.

Step 3. Turn on the signal generator. Set it to the intermediate frequency (generally 455 kilocycles) shown on the intermediate-frequency-amplifier transformer units.

Turn up the volume control on the signal generator to maximum output.

Step 4. Adjust the secondary of the last intermediate-frequency unit by turning its adjusting screw on top of the shield can. Use a screw driver with an insulated handle or a special aligning tool which has a wood or Bakelite handle and a metal bit.

Rough Tuning. Turn both the primary and secondary, adjusting the screws until the loudest signal is obtained.

Fine Tuning. Make the final adjustment of the last intermediate-frequency secondary with the signal-generator output set

so low that you can barely hear the signal. It is difficult to get an accurate setting with a loud signal.

Turn the adjusting screw past the loudest signal, first to the right and then to the left, reducing the motion each time until you are exactly on the point of the loudest signal. This is similar to the process of aligning the single-control receiver.

Now tune the primary by turning its adjusting screw in the same manner.

Step 5. Move the signal-generator leads to the grid of the mixer tube. Replace the grid lead on the intermediate-frequency tube. Adjust the first intermediate-frequency unit as you did the last.

Note that you first line up the intermediate-frequency unit *nearest the second detector.* Then you work toward the front of the set, doing the others in turn.

Step 6. After you have lined up the intermediate-frequency transformers and your instructor has checked them, disconnect the signal generator, attach the set to the antenna, and you are ready to learn how to tune the mixer and oscillator to bring in stations.

How to Operate the Circuit

An experimental superheterodyne circuit, set up by attaching set-board units together, is tricky to tune. The manufactured set is easy to tune, because the different tuning condensers are ganged, and the different circuits are carefully aligned in the factory.

Since you do not have ganged tuning control, you will have to tune both the oscillator and the mixer at the same time to get stations.

Step 1. Turn on the power supply. When the tubes heat, the set is ready to play.

Step 2. Tune for a station. As you tune the mixer with one hand, tune the oscillator with the other. Move the mixer control very slowly across the dial. At the same time, move the oscillator dial back and forth *near the setting* of the mixer dial. The oscillator should be set at a higher frequency than the signal. Its tuning dial is always a few points behind the mixer setting.

Continue until you hear a station. This set is quite selective, and so your tuning must be accurate.

Step 3. When you have learned to tune the superheterodyne circuit, replace the earphones by the audio amplifier and speaker.

How It Works

What are beat notes in sound? When two piano wires tuned to exactly the same pitch are set in vibration, you hear only one tone. But, if you stretch one of the wires more tightly, its note will be higher in pitch than before. Now, when you set both wires to vibrating, you will hear not only the tone produced by the first wire and the tone produced by the second wire, but you will also hear a third tone. The third tone is a slow, throbbing sound. It is called the *beat note.* When the two wires are vibrating at exactly the same rate, they are in resonance; no beat note is produced. This is called *zero beat.*

Let us say that the first wire has been tuned to a frequency of 256 cycles. This is the frequency of middle C on the piano. If the second wire is tighter than the first one, so that it produces a note of 260 cycles, which is a little higher than middle C, the third tone you hear is a low tone of four cycles, or the difference between the vibrating frequency of each of the strings (260 − 256 = 4). It sounds like a slow "m-m-M-m-m-m-m-M-m-m-m," swelling in loudness at regular intervals.

You can control the pitch of the beat note. If you tighten either wire, its pitch rises. The beat note changes, increasing in speed. You can thus change the rates of vibration until the beat note sounds higher, or until it can no longer be heard.

How do beat notes occur in a radio circuit? The action of the two strings in producing a beat note is similar to what goes on in a radio circuit in which there are two oscillations, each of a different frequency. The familiar whistle you hear when tuning a regenerative receiver with the set in oscillation is a beat note. It is caused by the carrier wave to which you are tuning beating with the oscillation produced by your set, forming what is commonly called the *carrier whistle.* This whistle is not the carrier; the carrier wave is a radio-frequency oscillation far above hearing.

The frequency of the beat note which you hear is equal to the difference between the carrier frequency and the frequency at which your set is oscillating. You cannot hear either of the original radio frequencies. If, for example, you have two radio frequencies

surging in a circuit, a carrier frequency of 100,000 cycles and a receiver-oscillation frequency of 101,000 cycles, you can hear neither of the two frequencies, since both are far above the hearable frequency. But the beat note produced by these two frequencies in your set will be at 1000 cycles a second (101,000 cycles − 100,000 cycles = 1000 cycles). You can hear a sound wave with a frequency of 1000 cycles.

You also could produce a beat frequency of 1000 cycles by using two other radio frequencies, one of 100,000 and another of 99,000 cycles, for example. Here the difference between the two frequencies again is 1000 cycles, and a beat note of the same pitch as the beat note in the preceding example is heard.

How can you control the pitch of the beat note? Just as you can change the beat note in sound, so you can change the pitch of the beat note in your receiver. One of the signals that helps to produce the beat note in your set comes in over the air. You cannot change its frequency. The other signal is generated in your own set. In the superheterodyne receiver you obtain a radio-frequency beat note. The second frequency that acts with the incoming signal to produce it is generated by the oscillator, which you can control. You can tune the oscillator in your set to get a beat note of any frequency you want.

How does the oscillator determine the beat note? When a 1000-kilocycle signal from a broadcasting station is received in the antenna, you should tune the oscillator of the superheterodyne receiver to a frequency of 1455 kilocycles. These two frequencies are then on the grid of the first detector tube. They blend and produce a surge of current 455,000 times per second, so that a new frequency is produced in the plate circuit. These surges make up a radio-frequency beat note of 455 kilocycles. You could also tune your oscillator to 545 kilocycles and get a beat note of 455 kilocycles (1000 kilocycles − 545 kilocycles = 455 kilocycles).

The intermediate-frequency stages amplify only a narrow frequency band. The intermediate-frequency transformers are tuned by the small trimmer condensers to a narrow band of frequencies near 455,000 cycles (455 kilocycles). When you adjust the trimmers to line up the set, you tune the coils and condensers to the same frequency near 455 kilocycles. This means that the amplifier will only allow a signal with a frequency of 455 kilocycles to

pass through the intermediate-frequency coils and tubes and will reject, or kill, any other frequencies. The intermediate-frequency stages are simply radio-frequency stages with fixed tuning.

Suppose a station operating on 1500 kilocycles is picked up by the radio-frequency part of your set. You then tune the oscillator to 1955 kilocycles to get a 455-kilocycle beat note. This beat note feeds through the intermediate-frequency amplifier to the second detector.

Questions

1. Can you hear the carrier wave from a radio broadcast station?
2. How can you find the frequency of the beat note produced by the two radio-frequency waves?
3. Suppose your set were receiving a station with a frequency of 900,000 cycles. At what two frequencies could you set your beat oscillator in order to produce a beat note of 455,000 cycles?
4. If you are receiving from a station with a frequency of 1,000,000 cycles, what frequencies will you apply to the grid of the mixer tube? Would there be one, two, or three frequencies in the beat circuit of the mixer?
5. If you are receiving from a station with a frequency of 120,000 cycles, is it better to tune the beat oscillator to a frequency above or below 120,000 cycles in order to get a beat note of 455,000 cycles? Give reasons for your answer.
6. What is a *test oscillator?*
7. What is meant by *attenuator control?*
8. When lining up the secondary of the last intermediate-frequency unit, why is it necessary to use a screw driver with an insulated handle?
9. Which intermediate-frequency unit is lined up first?

PART 3: HOW THE DIODE DETECTOR OPERATES

How does the diode detector work? Now let us see how the diode detector works. When the electrons in the diode tuning circuit surge as shown in Fig. 351, they draw electrons off the diode plate and make it positive. This draws electrons off the heated cathode of the diode tube. When the current in the coil reverses, it drives electrons onto the plate, making it negative, and no current flows through the tube (see Fig. 352).

The resulting electron flow through the tube is a rectified pulsating direct current, as shown in the wave picture, Fig. 353. The direct-current pulsations flow through the resistance *C*. As each surge is held up by the resistor, some electrons surge onto side *A* of the condenser. This drives electrons off side *B*. The condenser action tends to fill up the spaces in the wave-form picture when

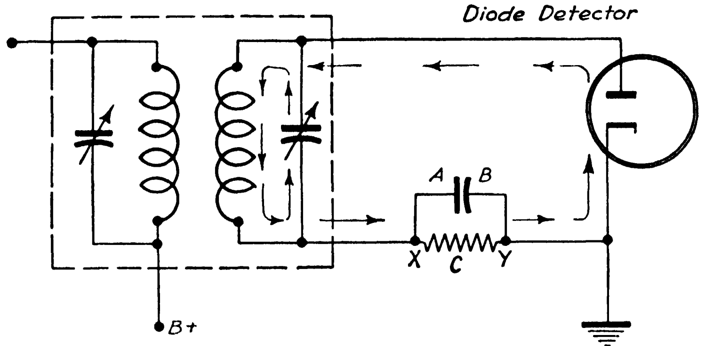


FIG. 351. When the electron surge in the tuning circuit is in this direction, electrons flow through the tube.

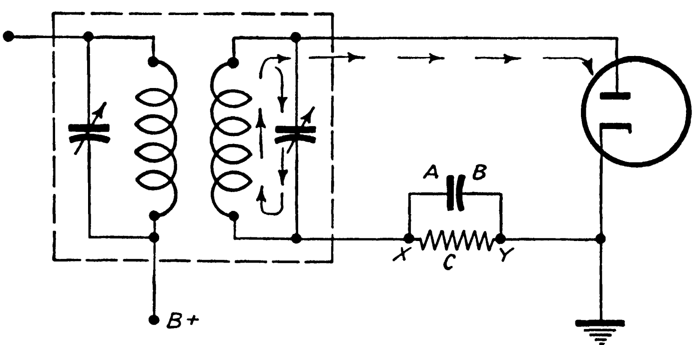


FIG. 352. When the tuning-circuit surge reverses direction and the electrons are driven onto the plate of the diode, no current flows through the tube.

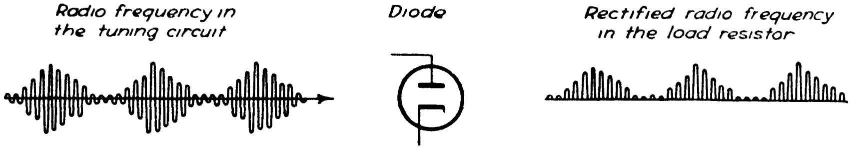


FIG. 353. Since the diode detector is a half-wave rectifier, it cuts off half of the radio-frequency wave. The output is still at radio frequency but now is in one direction. The radio-frequency surges are bunched in the load resistor and in the condenser into audio-frequency groups.

no current pulse comes from the diode tube. The condenser stores electrons from each surge and releases them into the circuit between surges. The result of this storage effect and of the slowing effect on the radio-frequency surges of the resistor connected across the condenser is to group the surges into audio-frequency bunches.

If a voltmeter were connected across this resistor, it would show a steady voltage when a radio wave carrying no program was being received. But when a radio wave carrying a program reached the circuit, it would show a varying voltage across the resistor because of the changing strength of surges caused by modulation. The changing quantity of electron bunches surging across the resistor would force electrons on the amplifier-tube grid and cause you to hear the program.

How do you control volume on the diode detector circuit? When an electron surge passes through the diode, there is a greater pressure of electrons at X than at Y (see Fig. 351).

You could connect a wire from X to the audio amplifier and use the resulting voltage to drive electrons on and off its grid. But by connecting a variable resistor at XY, you can use it as a volume control.

Note that this circuit is similar to the resistance coupling used between a detector and an audio amplifier.

PART 4: HOW AUTOMATIC VOLUME CONTROL WORKS

Improvement 1

Add automatic volume control (avc). The receiving set you have in your home probably uses the superheterodyne circuit you have just studied. But it has several added features that further improve its operation. One feature is the *automatic-volume-control* circuit.

What is one purpose of automatic volume control? The automatic-volume-control circuit has been built into most modern sets in one form or another. This circuit prevents or reduces annoying blasts of sound that occur when you tune across the dial with the volume turned up. In it electrons are fed from the second detector back to the radio-frequency amplifier and the intermediate-frequency amplifier to cut down a strong signal and to build up a weak one. As is indicated by its name, it works automatically,

the signal itself supplying the controlling voltage. Only one of the more common types of automatic-volume-control circuits is described here.

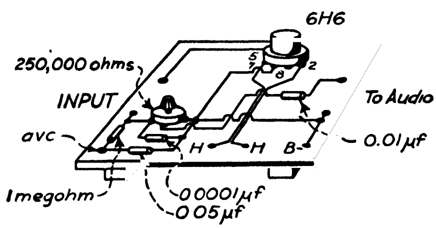


Fig. 354. Board layout for diode detector with automatic volume control (avc). The diode detector can be built with automatic volume control instead of building two separate boards.

How to Build and Wire the Circuit

Build this circuit on a small set board, and use it to replace the diode-detector unit. Arrange the parts as shown in Fig. 354, and wire the circuit as shown in Fig. 355.

Use the same tubes that were listed for the diode detector. The diode tube supplies the automatic-volume-control voltage. Note that only one section of the diode is used.

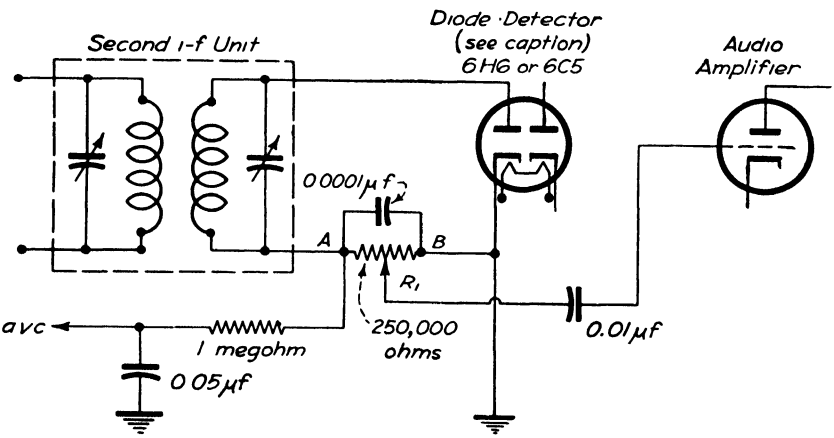


Fig. 355. Circuit diagram of the diode detector with the automatic volume control circuit added. Note that either one section of a duodiode may be used, or a triode tube may be used as a diode by connecting the grid and plate together.

How It Works

A strong signal from the antenna passing through the radio-frequency amplifier, the mixer, and the intermediate-frequency amplifier and reaching the diode detector applies a strong signal to the grid of each tube. A strong current in the second detector circuit flows through the resistor R_1 and produces a voltage drop

across it. There is more electron pressure at A than at B. The surge of current at point A makes the electron pressure high. This voltage through the wire marked "avc" in the circuit of Fig. 356 drives electrons on the grids of the radio-frequency-amplifier tubes. These extra electrons increase the negative grid bias on each tube and cut down the output of the set.

When the signal that reaches the second detector is weak and the automatic-volume-control voltage is low, there is less negative bias on the tubes, so that the signal through them becomes stronger.

The 1-megohm resistor and 0.05-microfarad condenser are a filter circuit that reduces variations in the automatic-volume-

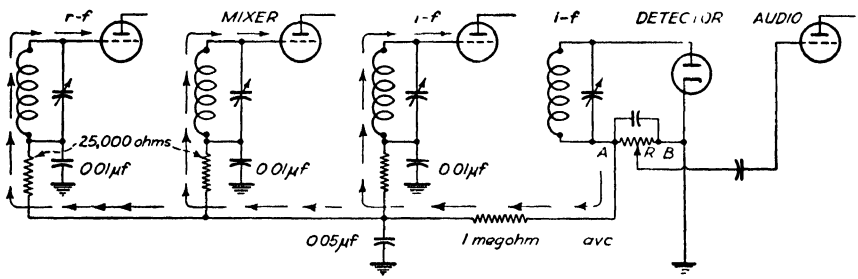


FIG. 356. This partial circuit shows the connection from the diode detector to the grid of the tubes, which give the volume-control action.

control voltage so that the negative bias on the grids of the amplifier tubes is steady and does not change with the strength of the modulating signal.

Improvement 2

Add a multipurpose tube. Instead of using separate tubes for the second detector (and automatic-volume-control) and for the first audio amplifier, these two jobs can be performed in one tube. The 6Q7G is such a tube. It combines two diodes and a triode in one glass or metal envelope (see Fig. 357 for the symbol). This is called a *duodiode-triode* (*duo-diode-triode*) *tube*.

Note in Fig. 357 how the circuit is connected to this tube to combine both diode detector and first triode audio amplifier.

There are several other points to note in this circuit. The resistor used for the diode load is made variable to act as a volume control. Voltage from the diode detector is led to the grid

of the triode through the 0.01-microfarad coupling condenser. The 1-megohm resistor is the grid leak for the audio amplifier.

The 2500-ohm resistor and the 10-microfarad condenser provide the grid bias for the triode audio-amplifier section of the 6Q7.

Why does it work? The theory of the operation of this combined tube is the same as that for the circuit in Figs. 317, 328, and 344.

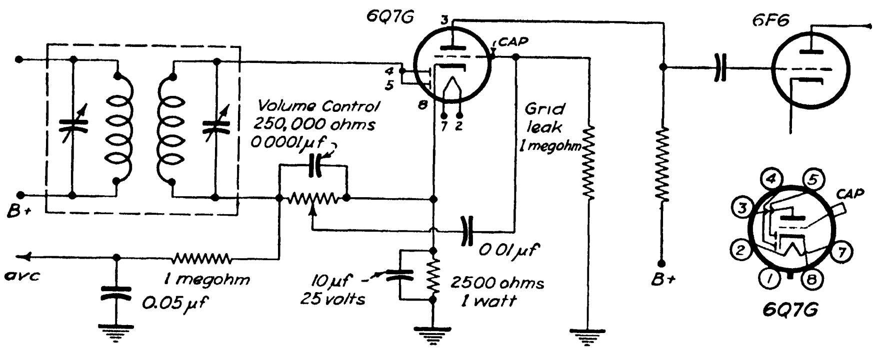


FIG. 357. Here the single tube, the 6Q7G, is used as a diode detector, as the source of the automatic volume control (avc) voltage, and as the first audio amplifier.

The new bias resistor and condenser, as connected here, provide a bias between the grid and cathode of the triode section of the tube.

Question

Give some advantages and disadvantages of automatic volume control.

Technical Terms

avc—Automatic volume control, which increases or decreases the sensitivity of the receiver as the signals vary in strength.

diode detector—A detector which uses a two-element, or diode, tube.

intermediate-frequency transformer—Part of the new tuning circuit that operates at high efficiency on a fixed frequency.

mixer—The first detector is often called a mixer because it mixes, or blends, the frequency set by the oscillator with the frequency of the incoming signal to produce a third, or intermediate, frequency.

second detector—Generally a diode detector which follows the intermediate-frequency amplifier. It has the regular detector job of regrouping the modulated radio frequency so that audio-frequency signals can be supplied to the audio-amplifier circuits.

CHAPTER 18

SHORT-WAVE SETS

When you studied radio waves and wave travel, you learned that a radio wave had two parts, or components. One, the ground wave, dies out after a relatively short distance, and the other, the sky wave, travels between the ionosphere layers and the earth over long distances.

For many years amateurs were the only large group using the short-wave bands. Because these bands were thought to be of no use for other services, they were turned over to amateurs for experimentation. Amateurs followed their hobby intensively, rebuilding their sets, trying new circuits, and making every effort to transmit and receive over greater distances. Many improvements came from their experiments, and they proved that the short waves held the secret of distance operation.

In this chapter you will learn the following things:

Part 1: The Features of Short-wave Sets
Part 2: How to Build a Two-tube Short-wave Receiver
Part 3: How to Construct Short-wave Plug-in Coils
Part 4: How to Adjust the Number of Turns on Plug-in Coils
Part 5: How to Build and Operate the Tuned-radio-frequency (trf) Amplifier
Part 6: Improvement for the Tuned-radio-frequency Short-wave Receiver

PART 1: THE FEATURES OF SHORT-WAVE SETS

The short-wave receiver is different from the long-wave receiver principally in the size of the coils used in the tuning circuits and in the size of the variable tuning condensers. The short-wave sets use the same basic circuits that you used in the receivers that you worked with in earlier chapters.

How can continuous-wave telegraphy be heard? Short-wave receivers for continuous-wave telegraphy use oscillating regenerative detector circuits or a separate beat-frequency oscillator, so that the broken carrier wave formed by the key at the transmitting station may be made hearable in the receiver. Continuous-wave

(c-w) telegraphy cannot be heard on the simple nonoscillating detector. Refinements in the tuning system are needed, because the amateur and other short-wave bands are narrow and require sharp tuning.

How are short-wave plug-in coils used? Since the amateur bands are separated and narrow, it is inefficient to wind one coil which will cover all of the bands. Instead, small coils are wound on forms that are fitted with pins, as on a tube base. Thus a coil which will tune over a narrow band of frequencies may be connected into the tuning circuit and easily exchanged for a coil of a different size when you wish to listen in on a different band of frequencies. In this way the same set will operate on many frequencies. The same tuning condenser is used for all bands. Fine tuning is done by a small condenser connected in parallel with the main tuning condenser and by using a slow-motion dial.

A favorite circuit for beginners is a detector-amplifier circuit which may be improved later by the addition of a stage of tuned-radio-frequency amplification. It may be further improved by thorough shielding to form a fairly satisfactory communication type of receiver for the experimenter.

This circuit is used by many amateurs for communicating over long distances by means of continuous-wave telegraph (code) or radio telephony.

Antennas for short-wave receivers are described in Chapter 23. A favorite antenna for these receivers is the doublet type. Many amateurs who have sufficient space have a separate doublet for each band in which they expect to operate.

Many manufactured sets are equipped with assemblies of individual coils connected to a multiple rotary switch, so that bands may be changed merely by turning the switch. Parts manufacturers' catalogues show many different designs for these assemblies.

PART 2: HOW TO BUILD A TWO-TUBE SHORT-WAVE RECEIVER

The two-tube set shown here is a set-board unit with a metal panel. It is a combined detector and audio amplifier that you will build in order to familiarize yourself with the problems that come from the close spacing of parts in a more compact set.

This set is easy to build and is a favorite with many amateurs for learning the international code and for listening to "press," or news, items sent out by commercial stations.

After you build a set, you can in a few weeks become familiar with its peculiarities of operation and learn to get the most out of it. It is sensitive enough to receive distant stations, and yet it is not so sensitive that it is hard to tune.

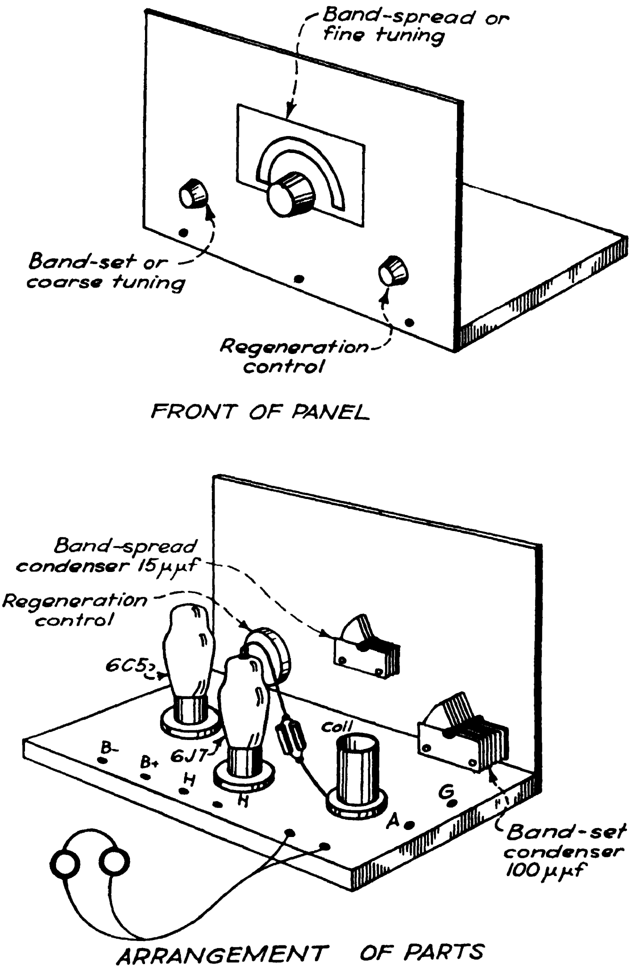


FIG. 358. A two-tube, short-wave set. This shows the arrangement of the panel and of the parts on the breadboard.

How to Build and Wire the Set

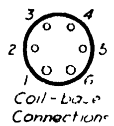
Tubes. Use a 6J7 tube in the detector circuit and a 6C5 tube in the audio-amplifier circuit.

Board Layout. Set the parts on the breadboard as shown in the board layout in Fig. 358. The detector-tube socket will be at the

left near the plug-in coil. The grid leads must be as short as possible. The coil must be at least $1\frac{1}{2}$ inches from the tube and from the condenser on the panel. Any convenient arrangement can be used for the parts of the audio amplifier.

New Parts

Coils. One or more plug-in coils, which you will wind, cover the frequency bands on which you wish to receive. Wind each coil on a six-pin form (see Fig. 361).



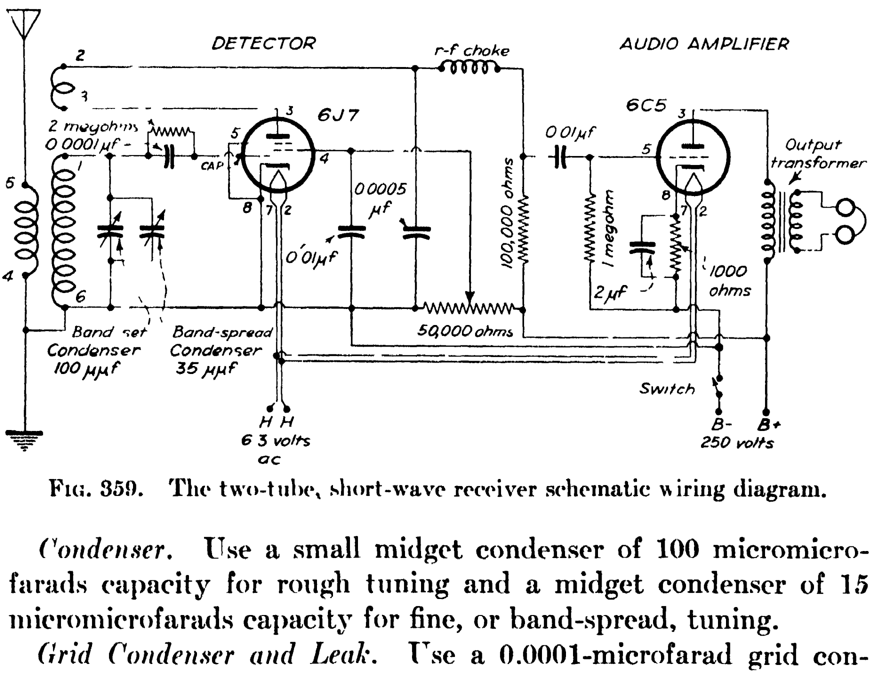


FIG. 359. The two-tube, short-wave receiver schematic wiring diagram.

Condenser. Use a small midget condenser of 100 micromicrofarads capacity for rough tuning and a midget condenser of 15 micromicrofarads capacity for fine, or band-spread, tuning.

Grid Condenser and Leak. Use a 0.0001-microfarad grid condenser with a 2-megohm grid leak in the detector circuit of this short-wave set.

Other Parts

The other apparatus in this set is the same as that used for the detector and amplifier circuits described in Chapter 16.

The Tuning Circuit

Follow the circuit diagram in Fig. 359 carefully. Run a wire from the grid coil to the grid condenser and grid leak and another from there to the grid of the 6J7 detector tube. Make these wires as short as possible, both for efficient operation and to prevent feedback from the plate wires. Keep wires from the grid coil to the tuning condensers as short as possible. Use a vernier dial for fine tuning on the band-spread midget tuning condenser.

Keep the plate leads short and as far as possible from the grid leads. Run the plate leads at an angle to the grid leads.

Wiring Precautions

Wire the short-wave set especially carefully. Sets operating on the higher frequencies are more affected by noise and poor connections than are the long-wave sets. Solder all joints. Mount all parts solidly, so that no vibration of any parts will occur during tuning.

Question

Compare the size of the grid condenser in short-wave sets with this condenser in broadcast sets.

PART 3: HOW TO CONSTRUCT SHORT-WAVE PLUG-IN COILS

Coils for the high-frequency bands (frequencies above 1500 kilocycles) are wound on smaller coil forms than are coils used for the low-frequency, or broadcast, receivers.

Building the Coils

You will build four coils so that their tuning ranges will overlap. The tuning range will start at about 1500 kilocycles and cover up to 18,000 kilocycles. You will see how coils using tube bases and tube sockets are constructed.

Make the coil forms. Obtain a 10-inch length of $1\frac{1}{2}$-inch (outside diameter) Bakelite tubing with a $\frac{1}{16}$-inch wall. Tubing of this size will just fit over a medium tube base. It may be possible to find tubing of the correct size from that which was used for a coil form in an old set. Coil forms, complete with pins, can be purchased at your radio-supply store if you do not wish to build them.

Saw the tubing into four pieces $2\frac{3}{8}$ inches long. Use a fine blade in the hack saw. Turn the tube while sawing to prevent the saw from chipping the edges of the tube. Smooth the ends of the tube with a coarse file. Finish by rubbing the ends on a piece of sandpaper laid flat on the workbench.

Fasten the coil form to a tube base. Slip the Bakelite tube over the tube base (see Fig. 360).

With a sharp point, mark the position of four holes about $\frac{3}{8}$ inch from the lower edges of the Bakelite tubing. Drill $\frac{1}{8}$-inch holes at the marks through both the Bakelite tubing and the tube base.

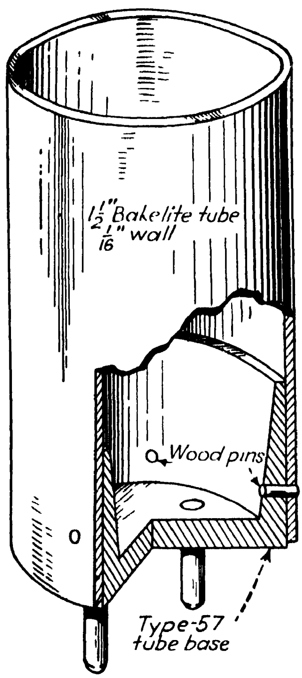


FIG. 360. A cutaway view showing how the coil form is fastened to the tube base.

Drive four hardwood pins into the holes, and cut them off flush with the surface of the tubing. These pins will hold the tube base firmly in position in the tubing. Metal pins would lower the efficiency of the coil somewhat.

How are the coils arranged? The grid coil is placed at the top of the coil form as far as possible from the metal parts of the base. The effect of metal near the grid coil is very appreciable at high frequencies. The efficiency of the plug-in coil with the grid coil at the lower end of the form is much less than when the grid coil is wound at the top of the form. The signals are weaker and the tuning is less sharp.

Because the plate and antenna coils are little affected by their nearness to the tube pins, they can be safely placed at the bottom of the coil form.

Wind the grid coil. Drill a small hole in the tubing about $\frac{1}{16}$ inch from the upper edge of the form, and fasten the wire at the end of the grid coil by passing it through the hole. Make this hole opposite the pin to which the grid end of the coil is to be soldered (see Fig. 361).

Scrape the insulation off the end of the wire for about $\frac{1}{2}$ inch. Slip the end of the wire through the hole in the tubing, run it

down through the hollow pin, and bend it back over the end of the pin to hold it while you are winding the coil; fasten the other end of the wire in a vise or around a nail. Wind on the grid coil the number of turns shown on page 428 in the Coil-winding Table, grid-coil column. Keep the wire tight. Count the turns by sliding a screw-driver blade lightly over the coil; you can hear a light tap as the blade drops from wire to wire.

After the proper number of turns is wound, allow about 6 inches more and then cut off the wire. Hold the end of the winding in place. Mark the position of the end of the grid coil in line with the pin shown in Fig. 361, and drill a hole. Slip the wire through the hole, and pull it tight; then run the wire through the base pin, and bend it over to hold it in place.

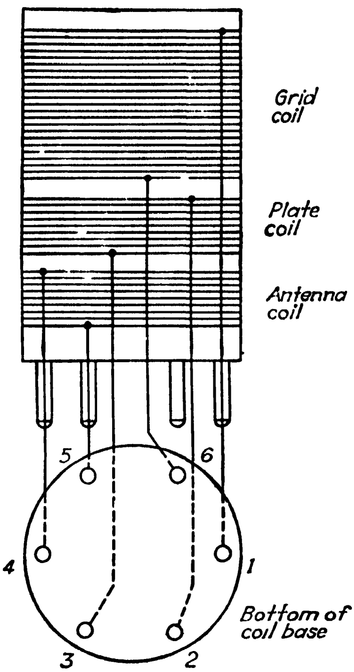


FIG. 361. This is the six-pin coil form and its wiring diagram.

Wind the plate and antenna coils. Now drill a hole to start the plate-coil winding about $\frac{1}{8}$ inch away from the grid coil (see Fig. 361 for the position of the hole). Use No. 28 or 30 wire. Wind both the plate and antenna coils in the same direction in which the grid coil is wound. Wind the antenna coil with the same size of wire as used for the other coils. Start it about $\frac{1}{8}$ inch from the plate coil.

Fasten the coils in place. When all of the coils have been wound, clean the wire ends extending through the base pins, and fasten them with a drop of solder.

Paint the coils with nail polish, clear lacquer, or coil dope to hold the windings in place, so that they will not loosen when the coils are plugged in and out of the socket.

Wind the 20-meter coil. The turns of the 20-meter grid coil must be spaced apart the width of the diameter of the wire to keep down distributed capacity. This is done by winding two

wires of the same size side by side. When the winding is finished, one wire is removed and the remaining winding is fastened in place with collodion, nail polish, lacquer, or coil dope.

The wire used on the 20-meter coil may be bare or covered with silk, cotton, or enamel, and may be No. 18 or 20.

Questions

1. Describe the most efficient method for fastening the Bakelite tubing onto the tube base.
2. Why is the grid coil placed at the top of the tube?
3. What is the disadvantage of using a small size of wire for the grid coil?
4. Explain how to space wind a 20-meter coil.
5. Why is spaced winding necessary?

Coil-winding Turns

The Grid Coil. The number of turns on the grid coil controls the range over which the set will tune when shunted with the given tuning condensers. At first, wind on more turns than you will need (see the Coil-winding Table); then cut off turns until the desired tuning range is covered.

The Plate Coil. The number of turns on this coil controls the feedback and the regeneration. Wind on too many turns (see table). Then cut off a turn at a time until the set goes into oscillation with the variable resistor at about the center of the dial.

The Antenna Coil. The number of turns on this coil is not important. Wind on enough turns to give a good transfer of energy to the grid and plate coils. Try adding to the number of turns to see if the signals will be louder.

Too many turns or too close spacing between the antenna coil and the grid coil will cause broad tuning and may cause dead spots where the set will not oscillate. If there is too much coupling

COIL-WINDING TABLE

Frequency	Grid coil, turns	Plate coil, turns	Antenna coil, turns	Wire size for grid coil, number
1750	60	30	10	28, double silk cover
3500	30 35	10	6 8	22, double silk cover
7000	14	5	4 6	22, double silk cover
14,000	5*	5	5	18, enameled cover

* Must be space wound (see page 427).

between coils, increase the space to about $\frac{1}{4}$ inch, or take off a few turns.

The connection of each coil to the base pins is made in such a way that crossing is avoided in the set wiring.

Questions

1. The range over which the set will tune is controlled by the number of turns on which coil?
2. The feedback and the regeneration are controlled by the number of turns on which coil?

PART 4: HOW TO ADJUST THE NUMBER OF TURNS ON PLUG-IN COILS

What is the effect of different sizes of wire? You will find the number of turns for a coil by winding on too many turns and then removing turns until the set works well. If the wire size given in the table is used, little adjusting will be necessary. Possibly, the set will not oscillate at all or will oscillate so violently that it will squeal.

Here is a handy rule for selecting different wire sizes: If you use smaller wire than that specified, wind on the number of turns called for in the table. The effect of using smaller wire will be the same as winding too many turns on the coils. Turns can then be cut off to make the coils work properly. If larger wire is used, wind on 2 extra turns for every 10 turns called for in the coil-winding instructions.

Experiment with the first set of coils. It is a good idea to wind test coils with scrap wire. The first coils will then be experimental, and you will not feel particular about their appearance and will not be reluctant to add or cut off turns. After the first coil is wound and adjusted, a better looking coil of exactly the same number of turns can be wound on the same form.

Adjust the plate coil first. All three coils must be wound in the same direction; unless this is done, the circuit will not oscillate. The set must oscillate to receive code and to locate short-wave stations, especially the distant ones. Reverse the connections to the plate coil if the set will not oscillate.

Adjust the B voltage. Use the correct B voltage for the 6J7 tube (see Fig. 359). If the B voltage is too high, the set will squeal and will be hard to adjust for sensitivity. It will go into oscillation too easily.

If too many turns are wound on the plate coil, the set will oscillate too strongly and may squeal or "pull over" into oscillation. This is shown by either a bad audio howl or too loud a pop in the phones when the grid wire is touched with the finger.

Cut off turns, one turn at a time, until the set oscillates gently with the resistor set half in. Too large a grid leak will cause oscillation to start with a loud bang instead of a soft thud.

What is the effect of too few turns? When too few turns are wound on the plate coil, the set will not oscillate. Oscillation will not start even when the resistor control is turned to the low-resistance position or when the B voltage is increased. The remedy is to add about twice as many turns of wire as you think you will need, so that there will be extra turns to cut off. Wind the extra turns on top of the coil if necessary.

Now adjust the grid coil. The number of turns on the grid coil and the capacity of the tuning condenser determine the width of the frequency band over which the set will tune. The maximum and minimum capacity of the tuning condenser are fixed, and so the only way you can change the width of the frequency band over which the set will tune is to change the number of turns on the grid coil.

Wind more turns on the grid coil if you want the coil to reach a lower frequency. Take off turns if it tunes to too low a frequency.

It will be found that changes in the number of grid-coil turns have some effect on regeneration. Adjust the number of turns on the plate coil after changing the grid coil, if this is necessary.

Adjust the antenna coil. The antenna coil must have turns enough to induce in the grid and plate coils the voltages that will operate the set. Too few turns will not supply enough energy to the set to enable you to hear the signals in the phones. The set will not be sensitive. Weak and distant signals will not be heard.

Putting too many turns on the antenna coil makes the coupling so close that tuning is broad, and it is hard to separate stations with the tuning condenser. The set will go out of oscillation at different places on the dial. When this happens, either remove turns from the antenna coil or space the coil farther from the plate coil to loosen the coupling. The antenna coil is the least difficult of the three coils to adjust.

Adjust the high-frequency coils. These coils are the most difficult to adjust. At the higher frequencies, feedback is greater. These two coils often go out of oscillation at one or more places on the condenser dial. This occurs when the antenna is in resonance with the grid coil. The antenna circuit then draws enough energy from the set to stop oscillation.

Oscillation can be started again by increasing the plate voltage or by adding to the turns on the plate coil. Change in plate voltage is not desirable. The plate voltage should be the same for all coils. If adding to the turns not only starts oscillation but also starts howling, some other method must be found to keep the set oscillating. For example, the antenna may be shortened or lengthened a few feet. When the length is right, the set will oscillate over the whole condenser range. A small variable condenser in series with the antenna has the same effect but adds another adjustment. Try changing the number of turns on the antenna coil. Also rewind the antenna coil farther from the plate coil. This will make looser coupling between the coils and may solve your trouble.

Questions

1. If you are using smaller wire than is listed in the table, will it be necessary to wind on more or fewer turns than are called for?

2. How is the operation of a set affected by insufficient turns wound on the plate coil?

3. Is the frequency band over which a set will tune controlled by the condenser or by the number of turns on the grid coil?

4. Explain why sets on the high-frequency band will often go out of oscillation at certain places on the condenser dial.

5. Make a list of methods for correcting faulty oscillation on short-wave sets.

PART 5: HOW TO BUILD AND OPERATE THE TUNED-RADIO-FREQUENCY (TRF) AMPLIFIER

Why is a radio-frequency amplifier added? When you used a radio-frequency amplifier while studying alternating-current sets in Chapter 16, you found that this amplifier increased the sensitivity and range of the receiver. If you now add a radio-frequency amplifier to your short-wave receiver, you will increase the receiver's sensitivity to weak signals and also its operating range. The tuned-radio-frequency (trf) receiver is an excellent set to experi-

ment with as you study the construction and operation of amateur receivers. It is relatively easy to build and to operate. The addition of the tuned-radio-frequency stage also sharpens the tuning of the receiver and makes it more selective. Such a set is normally operated with earphones when you are receiving amateur signals. You can adapt it as a broadcast receiver by using the proper coil sizes and adding a power-amplifier tube and a dynamic speaker.

While the set described here is not the last word in efficiency, it is efficient enough for long-distance amateur telegraph and telephone use, and it is inexpensive and easy to tune. It uses parts in its construction which can later be used for a more efficient set.

You will find it convenient to build this set first in three units. Mount the detector and the audio amplifier on one baseboard and the radio-frequency amplifier on a second baseboard (see Fig. 362). The power supply is a separate unit. This scheme allows you to get the detector-amplifier set in efficient operation before you attempt to build and line up the radio-frequency amplifier. The circuit is laid out breadboard style so that you can experiment with it easily. The parts are separated enough to avoid feedback from coupling between stray radio-frequency or magnetic fields.

How is the set shielded? You found in Chapter 12 that shielding was needed in regenerative receivers to avoid the effect of body capacity, which changes tuning and feedback as you move your hand near the tuning and control knobs.

Since the tuned-radio-frequency set you are now building will operate on the higher frequencies, you will find the effect of body capacity and stray fields to be greater than with the sets you built and operated for the broadcast frequencies. It will now be necessary to build a better shielded set than before and to use greater care in wiring.

There are several ways to reduce this body-capacity effect. One way you learned in Chapter 12 was to connect the rotor of the tuning condenser to B minus. Another way was to place a grounded metal plate just behind the tuning dials.

Many shielding problems are easily solved by mounting the controls on a grounded steel or aluminum panel. If you use glass tubes, you will need individual copper or aluminum shield cans over the radio-frequency tube and the detector tube. Each tube shield must be connected to the B-negative wire. The B-minus

terminal should also be wired to ground. If you use metal tubes, you will need no shields, since the shell of the metal tube acts as a shield.

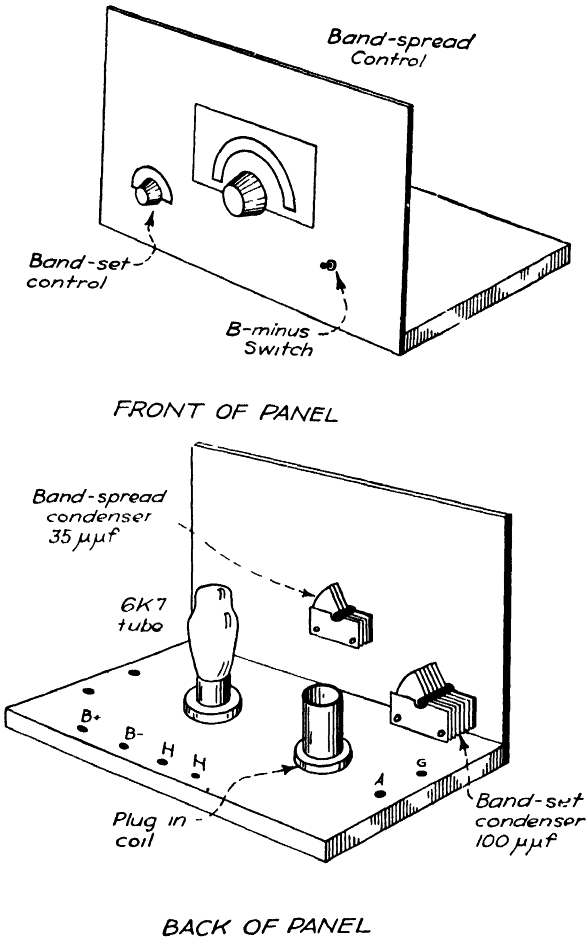


FIG. 362. The radio-frequency amplifier for the short-wave receiver. This shows the arrangement of the panel and of the parts on the base.

Place the parts of this set as shown in the board layout (see Fig. 362), with the radio-frequency coil far enough from the detector coil to prevent feedback and poor tuning. The plug-in coils seldom need shielding unless you are working with an extremely sensitive receiver. A coil shield may even be harmful. If the shield is too close to the coil (too small in diameter), the metal

will absorb energy from the magnetic field of the coil and cut down on the strength of the signal. You will need no coil shield on this receiver.

How to Build and Wire the Radio-frequency Amplifier

The Panel. Use a sheet of $\frac{1}{16}$-inch aluminum about 6 inches high and 9 inches long. Aluminum is pleasing in appearance, easy to drill and cut, and not too expensive. Such a panel is rigid enough to support the tuning condensers and resistor. Other suitable materials for the panel are galvanized iron, brass, or masonite. Brass or iron sheets $\frac{1}{16}$ inch thick are stiff enough to support the apparatus mounted on them. Masonite is popular because it is so easy to work and because it is inexpensive. Foil cemented to the back of the masonite panel is an effective shield.

Questions

1. To what must the tube shields be grounded?
2. Is the band-spread condenser connected in series or in parallel with the main tuning condenser?
3. List the parts of one stage which must be shielded from certain parts of the next stage.
4. Is a copper shield or an aluminum shield better for radio-frequency shielding?
5. Is iron better than copper for audio-frequency shielding? Which metal is better for radio-frequency shielding?

The Panel Controls. The kinds of dials you expect to use determine the position of the mounting holes on the panel. You will need two tuning dials for this set. You can use a small knob and pointer for the band-set condenser. Use a slow-motion dial for the band-spread condenser in the center of the panel.

Mount a toggle switch on the panel to cut off the B voltage while you are experimenting with your set.

Drill three holes near the lower edge of the panel for roundhead wood screws to fasten the panel to the edge of the wood base.

Position of the Parts on the Baseboard

Place the parts on the baseboard as shown in the board layout (see Fig. 362).

Place the band-set condenser at the left of the panel. Place the plug-in coil behind the band-set condenser, so that the tuning circuit leads will be as short and direct as possible. Place the socket of the radio-frequency amplifier tube near the coil socket so that

the grid lead will be short. Fasten the parts in place with wood screws.

How to Wire the Set

Use insulated push-back wire for making connections between parts. Run the connecting wires from part to part as directly as possible. Keep all wires as short as is practical. In this set you

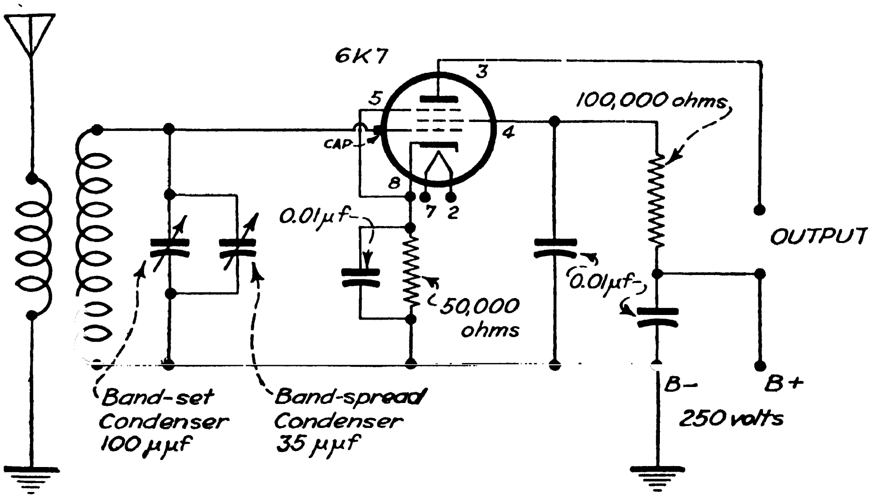


FIG. 363. The schematic diagram of the radio-frequency amplifier for the short-wave receiver.

will no longer be able to follow the appearance of the circuit diagram. The circuit is shown in Fig. 363.

How to Operate It

The operation of this set is no different from that of other regenerative circuits you have studied. Attach the heater and B-supply wires to the radio-frequency amplifier, and attach its output to the A posts and ground posts on the detector-amplifier board. Turn on the power supply. Your set is in operation as soon as the tubes warm up.

Step 1. Adjust the detector regeneration control so that the set is in oscillation.

Step 2. Tune the detector band-set condenser (see Fig. 362) until you hear the carrier whistle of a station. You will probably tune through a group of whistles, because this large condenser cannot be set accurately on any one signal.

Step 3. Tune in the station you wish to hear with the detector band-spread slow-motion control. You will find it relatively easy to pick out a station with this control. You will do most of your tuning with the band-spread dial.

Step 4. Now repeat the tuning with the radio-frequency amplifier controls. You will find that tuning the radio-frequency amplifier causes the signal to increase greatly in strength. As you become acquainted with this set, you will find that the radio-frequency amplifier and the detector tune together.

PART 6: IMPROVEMENT FOR THE TUNED-RADIO-FREQUENCY SHORT-WAVE RECEIVER

Improvement 1

Mount the parts on a metal chassis. The chassis is an open metal box (see Fig. 364). You can either purchase or build the chassis. Purchased chassis are made of 20-gauge cadmium-plated steel. This set can be mounted on a standard chassis $1\frac{1}{4}$ in. $\times$ 7 in. $\times$ 9 in. in size. You can make the chassis of 20-gauge galvanized or tinned (bright) sheet metal (see Fig. 464 for the cutting and bending diagrams).

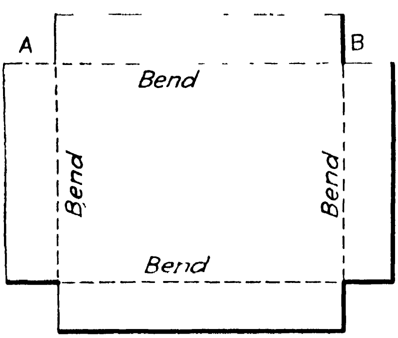


FIG. 364. The chassis layout. Draw on the chassis metal the shape shown here. Cut out the corners, bend on the lines, and you have a chassis for your set.

You can mount the three-tube set on a single metal chassis and save considerable space. This arrangement is also convenient to wire. Mark the size of the sheet metal as shown in Fig. 364. Draw lines $1\frac{1}{2}$ inches from the edges of the metal. This is the depth of the chassis. Cut out the four corners, and bend on the dotted lines to form the chassis.

The Panel. Fasten the panel to the front of the chassis with four small roundhead machine screws. Cut holes through the chassis for the sockets with a knockout punch or a circle cutter.

The Wiring. Drill $\frac{1}{4}$-inch-diameter holes for wires which must run through the chassis. Mount the wafer sockets for the tubes under the chassis by means of two small machine screws.

Only the plug-in coils, the tubes, and the tuning condensers are placed on top of the chassis. The wiring is done under the chassis. In this way, the wires which carry radio frequencies are shielded from the tubes and from the coils. The audio transformer may be placed above or below the chassis.

Any part in the circuit which is to be grounded is soldered to soldering lugs bolted to the chassis.

Wire the set with "push-back" wire.

Improvement 2

Place the power supply on the same chassis. If you use this tuned-radio-frequency set for amateur operation or wish to dress it up in appearance, you will find a separate power supply and the necessary connection wires a nuisance. They are unsightly and in the way on the operating table. You can save space and wiring by using a larger chassis and mounting the power supply on the same chassis as the set.

Select a well-shielded transformer for the power supply. The shielding will reduce hum. Cut a hole through the chassis for the connection lugs, which are generally on the underside of the transformer.

Question

Why are such parts as the plug-in coils and tuning condensers placed above the chassis?

Technical Terms

band set—A term referring to the condenser used for coarse tuning. It is set to the highest frequency on the band. Tuning in the relatively narrow band is done with a second condenser connected in parallel across the band-set condenser.

band spread—The low-capacity condenser used for fine tuning. It spreads the band because the stations are farther apart in its dial.

chassis—The open metal pan on which the parts of a set are mounted.

c-w—The abbreviation for continuous wave, a term used to describe the form of telegraphy widely used by amateurs and commercial radio-telegraph stations for long-distance communication.

plug-in coils—Coils on forms with pins and base similar to those used on tubes. Each plug-in coil covers a narrow section of the frequency bands on which the set will operate. The plug-in coils are found in sets built by experimenters. Commercially built sets use a special type of rotary switch and many coils to avoid the inconvenience of changing coils.

CHAPTER 19

PUBLIC-ADDRESS UNITS

A microphone has a peculiar fascination. Set one on a table, and it always attracts attention. Attach it to an amplifier and a speaker, and you have a public-address unit that will boom out your voice.

A public-address unit is relatively simple. It consists of a microphone, a preamplifier to build up the weak voice-current changes in the mike circuit, a power amplifier to build up final volume, a power supply, and a speaker.

You have studied and used all these units except the microphone. You can use in your public-address set the same amplifier units that you have used for either the battery or the alternating-current receiver. For the power supply, you can use either of the two types (with or without transformer) that you studied in Chapter 14, "Power Supplies," or you can use batteries.

You can make the simple unit into a high-quality public-address set by adding several refinements. You can add different tone controls to improve music quality. You may also wish to substitute a phonograph pickup for the microphone, so that your amplifier can be used to play your favorite records. You may wish to use more than one microphone, so that several persons can talk over the public-address unit and take part in a quiz type of program. You can arrange your set so that it has one microphone for an announcer, another microphone for a piano, and another for a singer. Many other combinations are also possible. You can use several loudspeakers to cover different rooms or to give good sound coverage in an auditorium.

Many who plan to make radio their vocation get their start in business by renting out public-address units. These units are always in demand to play records for dances. Public-address units are also used at political meetings to carry the speaker's

voice to all parts of the auditorium. Church and social gatherings find many uses for public-address units. A microphone installed in a pulpit helps carry the minister's voice into all parts of the auditorium in a church that has poor acoustic properties. Call systems between offices are a widely used form of public-address unit. Installing or renting these units is a good source of income for many a radioman.

In this chapter you will learn the following things:

Part 1: The Parts of a Public-address Unit
Part 2: The Characteristics of Microphones
Part 3: Several Types of Microphones
Part 4: How to Build a Simple Public-address Set
Part 5: How to Build a More Powerful Public-address Amplifier
Part 6: How to Attach a Record Player to Your Amplifier
Part 7: How the Phase-inverter Audio Amplifier Operates
Part 8: How to Connect Distant Loudspeakers
Part 9: How to Build an Interoffice Intercommunicator Circuit
Part 10: The Explanation of Power-amplifier Bias

The group of microphones you will study in this chapter introduces a new group of symbols (see Fig. 365). It is difficult to show a picture of the different microphones, because the same case shape is often used for several kinds of microphones. The carbon and the velocity have distinctive cases.

PART 1: THE PARTS OF A PUBLIC-ADDRESS UNIT

A block diagram will show in simple form the different units of a public-address set (see Fig. 366). Although this simple unit can be easily assembled, it illustrates well the action of a public-address unit. Examine the block diagram, and learn the different parts of the public-address unit and the job done by each.

The *microphone* picks up sound waves from the air and converts them into weak pulsating currents and voltages.

The *preamplifier*, or speech amplifier, builds up the pulsating voltages delivered by the microphone until they are powerful enough to operate a power audio amplifier.

The *power amplifier* further builds up the signals until they are powerful enough to operate a speaker. The speaker uses the alternating current delivered by the power amplifier to reproduce sound.

The *power supply* is the source of filament, or heater, current and the high voltage for the plates and screens of the tubes.

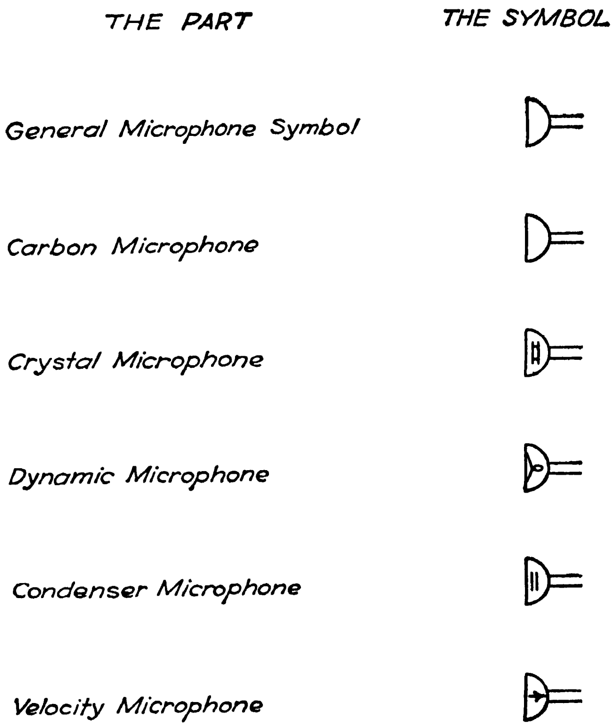


FIG. 365. New symbols first used in this chapter.

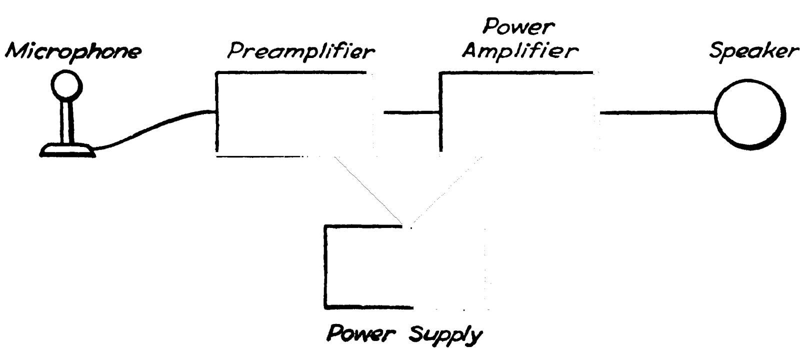


FIG. 366. The public-address set is made up of these units, all of which you have studied except the new microphone units.

PART 2: THE CHARACTERISTICS OF MICROPHONES

In your study of radio you should become familiar with the several types of microphones and know some of their general characteristics. These types are the carbon, the crystal, the dynamic, the velocity, and the condenser microphones. The single-button carbon microphone is used for portable purposes, such as walkie-talkies, police cars, taxis, trucks, busses, and trains. The crystal microphone is most widely used by radio amateurs and in public-address work. The dynamic, the velocity, and the condenser microphones are used in broadcast studios and in very high quality public-address work.

How should a microphone be selected? In this chapter you will study standard forms of microphones and become acquainted with their characteristics. You will want to know something about their cost, their sensitivity, their frequency response, their ruggedness, and any special characteristics which may help you to select a type for a definite use.

Cost. Cost is important if you are selecting a microphone for use with your public-address amplifier or for an amateur or commercial radio-telephone transmitter. The carbon microphone is the cheapest and the condenser the most expensive, the others ranging in price in the order in which they were mentioned above.

Sensitivity. Sensitivity determines the number of stages of audio amplification between the microphone and the power audio amplifier. The carbon microphone needs the least amplification and the condenser the most.

Frequency response. This determines the type of microphone to select to pick up fine music or to use with an ordinary telephone. *Frequency response* refers to the range of frequencies a microphone will handle. The microphone used to broadcast a symphony must have a higher frequency response than one used for an ordinary telephone. It must be able to handle the high frequencies which give brilliance to the music. A telephone microphone handles the much lower frequencies of ordinary conversation. The carbon microphone has the poorest frequency response and the condenser the best.

Ruggedness. This is important in selecting a microphone for the rough handling a walkie-talkie, a car, or a rental public-address set

will receive. A more delicate type of instrument can be used in laboratories or broadcast studios. The carbon microphone is the most rugged and the condenser the most delicate.

Each microphone is described in detail in Part 3. You can learn there the advantages, the construction, the characteristics, and the operating principles of each type of microphone.

How is the microphone coupled to the preamplifier? The different microphones you will study must be connected to the preamplifier through a coupling circuit. The purpose of this circuit is to match the impedance of the microphone to the very high impedance of the preamplifier tube.

The low-impedance microphones—the carbon, the dynamic, and the velocity —are coupled to the preamplifier grid through a transformer. The transformer is mounted in the microphone housing (dynamic and velocity) but is separate for the carbon microphone. The primary of the transformer has approximately the same impedance as the microphone, from 5 to 10 ohms, and the secondary has a very high impedance in order to work well with the high impedance of the grid circuit.

The crystal and condenser microphones have very high impedance, so that they can be coupled directly to the grid through a fixed condenser. The coupling circuit for each microphone is shown with the description of the microphone in Part 3.

PART 3: SEVERAL TYPES OF MICROPHONES

Carbon Microphones

Carbon microphones are the least expensive of the types you will study. They will reproduce sound with reasonably good quality. The carbon microphone requires less amplification between the microphone and the power-amplifier tube than other types of microphone. A disadvantage of this microphone is the background hiss caused by variations of current flow between the carbon grains.

The transmitter used on the telephone in your home is a single-button carbon microphone designed for rugged service in the hands of persons who are not accustomed to handling sensitive instruments.

How is the microphone made? The operating parts of the single-button carbon microphone shown in Fig. 367 are a paper

cone and an insulating cup which contains tiny carbon granules. Two contacts, one mounted on the paper cone and the other inside the insulating cup, are used to connect the microphone to the preamplifier circuit.

Examine the circuit shown in Fig. 368 for the single-button microphone. The external voltage of 1.5 volts required for this microphone may be obtained from an ordinary flashlight cell. Either the cell should be removed or the microphone plug pulled out when the set is not being used, so that the cell will not run down.

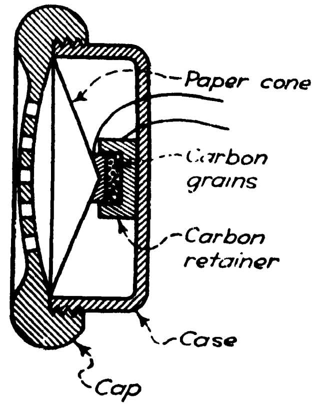


Fig. 367. The construction of a single-button carbon microphone.

How does the single-button microphone work? Direct current from the battery, as shown in Figs. 367 and 368, flows to the diaphragm through the carbon grains and the microphone-transformer primary back to the battery. Sound waves (see Fig. 369) cause the diaphragm to move. The compression part of the sound wave pushes the diaphragm in one direction, and when the rarefied

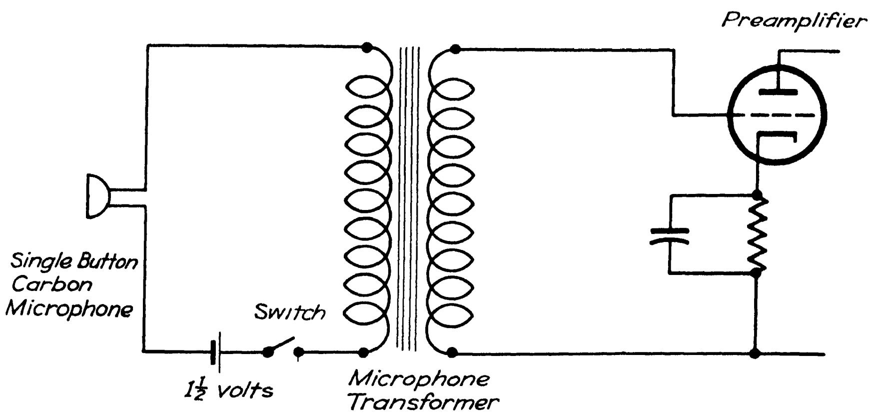


Fig. 368. The circuit for a single-button carbon microphone.

part of the sound wave arrives, the diaphragm moves in the other direction. When the diaphragm moves during the compression part of the sound wave, the carbon granules in the insulating cup

are pushed together. This reduces the resistance of the granules to the passage of the battery current. Current can flow more easily through closely packed grains than through grains that are loosely packed. At this instant more current flows through the microphone, and this surge induces a voltage in the secondary circuit of the transformer. During the rarefied part of the sound wave, the microphone current becomes smaller, and a voltage in the opposite direction is induced in the transformer secondary. Thus the sound wave causes an alternating voltage to appear between the grid and cathode of the preamplifier tube.

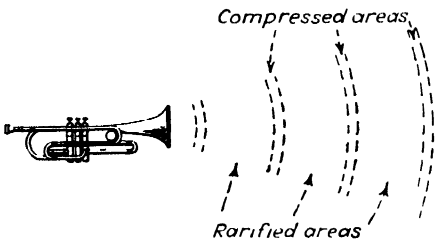


FIG. 369. Sound waves cause the diaphragm of the microphone to move.

The Crystal Microphone

This is one of the best types of microphones. It will stand ordinary handling, but severe jars will break the mounting or the Rochelle-salt crystals. Heat also will damage the Rochelle-salt crystals. No external power is required for this microphone, and since it is fairly inexpensive, it makes a fine instrument for general use. It has very good frequency response.

How is the crystal microphone made? Two Rochelle-salt-crystal slabs about 0.01 inch thick, with foil cemented on both faces, are clamped together to form a tiny sound cell (see Fig. 370).

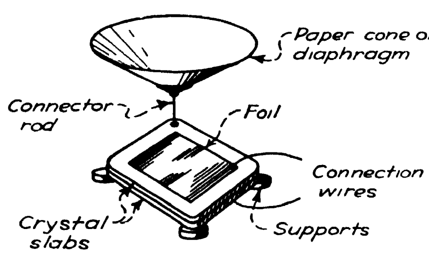


FIG. 370. This is the operating mechanism of a crystal microphone.

Circuit. As shown in the circuit in Fig. 371, a crystal microphone is connected to the grid of the preamplifier stage through a coupling condenser. No external voltage is needed with this circuit.

How it works. Sound waves cause the slabs to vibrate and to bend apart in the center. This vibration sets up a weak voltage.

Several of the sound units are connected together to deliver more voltage than would one unit.

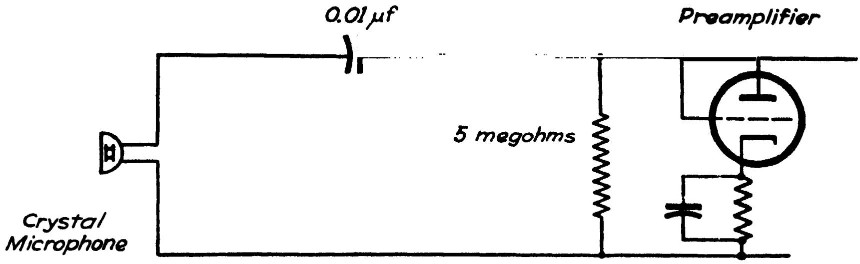


FIG. 371. The circuit for a crystal microphone.

Questions

1. Is the crystal microphone very rugged?
2. Compare its cost with that of the other types.
3. Is it directional?
4. Does this microphone have good tone quality?
5. Do you need to connect a battery in the crystal circuit?
6. What type of coupling is best between the amplifier stages for this microphone?

Dynamic Microphones

The dynamic microphone is a rugged and not too expensive instrument. It has excellent frequency response and is about as expensive as a crystal microphone.

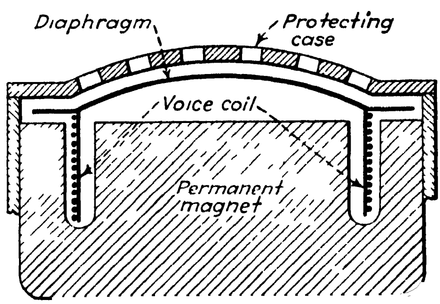


FIG. 372. The dynamic microphone and its internal construction.

How is the dynamic microphone made? This microphone is similar in many ways to the permanent-magnet (p-m) dynamic speaker. (The permanent-magnet dynamic speaker is often used as a microphone.) A coil is mounted on the diaphragm as in a dynamic speaker (see Fig. 372). The powerful magnetic field in which the small coil moves is supplied by a heavy permanent magnet.

Circuit. The voice coil, as shown in Fig. 373, is connected to the primary of the microphone transformer. The use of the permanent magnet makes unnecessary a field-supply current.

How it works. Sound waves cause the diaphragm to move back and forth. This causes the coil to move in the powerful magnetic field of the permanent magnet. The variations in the motion of the moving coil follow the variations in the sound waves and produce alternating currents in the primary of the microphone transformer. A current is produced in the wires of the voice coil attached to the diaphragm as the coil moves in the magnetic field.

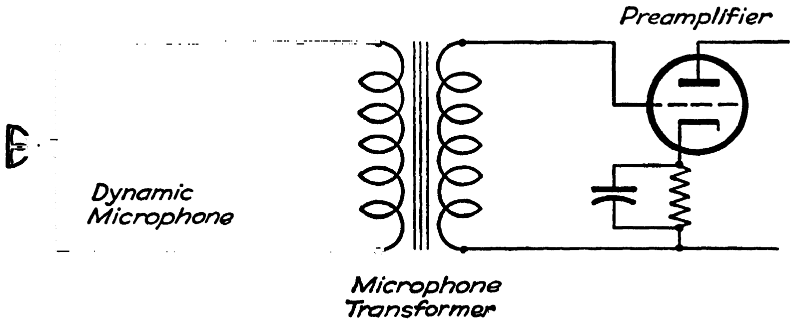


FIG. 373. The circuit for the dynamic microphone.

Questions

1. Is the dynamic microphone a rugged instrument?
2. Compare its cost to that of other types.
3. Is it directional?
4. How much amplification is needed?
5. Do you need to connect a battery in the circuit?
6. Compare its tone quality with that of the other types.
7. Compare its operation with that of the dynamic speaker.

The Condenser Microphone

The condenser microphone is a good all-purpose instrument which has the finest frequency response of the microphones you will study. This instrument is delicate, however, and should not be jarred. It is quite expensive, which limits its usefulness in the amateur and experimental field. It is not especially directional. It requires more amplification than the carbon button microphone.

How is a condenser microphone made? A stretching ring similar to that used in the carbon microphone stretches, or supports, a 0.001-inch-thick duralumin diaphragm at a distance of about 0.001 inch from a heavy metal back plate. The duralumin sheet is insulated from the metal plate by an insulating ring to form a condenser (see Fig. 374). No dust or moisture must get between

the diaphragm and the plate. The mounting for this instrument must be carefully made to prevent any shocks from reaching the diaphragm.

Circuit. The wiring diagram (see Fig. 375) shows that 180 volts must be connected across the diaphragm and the plate of the condenser microphone.

How it works. Sound waves strike the diaphragm and cause it to move nearer or to spring away from the back plate. When the diaphragm is near the back plate, the capacity of the condenser is increased, and a surge of current flows into it from the microphone power supply. When the diaphragm springs away from the back plate, the capacity of the condenser is reduced. Since it will then hold less charge, the excess electrons are forced back into the microphone battery. These resulting variations in voltage across the 3-megohm resistor reach the grid of the preamplifier tube through the 0.01-microfarad coupling condenser.

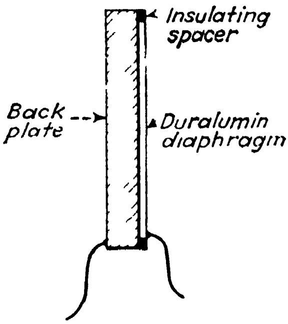


FIG. 374. The internal construction of the condenser microphone.

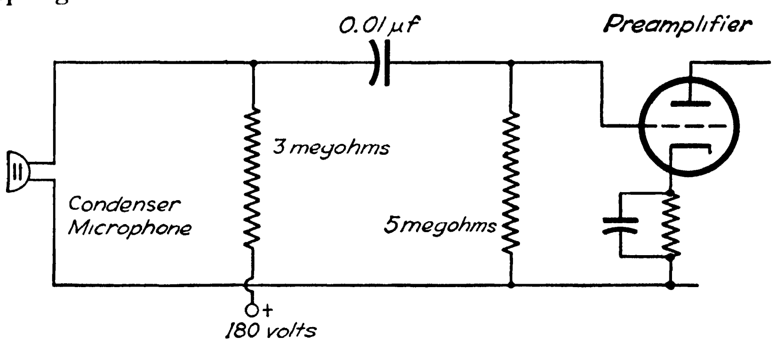


FIG. 375. The circuit for a condenser microphone.

Questions

1. Is the condenser microphone a rugged instrument?
2. Is it a very expensive type of microphone?
3. Is it directional?
4. How many volts must be used across the condenser?
5. Does the current increase or decrease when the diaphragm springs away from the other plate?

6. Is the capacity of the condenser greater or smaller when the diaphragm springs away from the other plate?

7. How does the tone quality of the condenser microphone compare with the double-button type?

Velocity Microphones

The velocity microphone is a very rugged instrument with very good frequency response. It is about as expensive as a dynamic microphone. It has the advantage of needing no microphone battery. It is very directional. This is particularly desirable for broadcast-studio use.

How is the velocity microphone made? The velocity microphone is essentially a thin corrugated duralumin ribbon suspended in a strong magnetic field.

The field is supplied by a heavy permanent magnet arranged so that the ends of the cores form a long, narrow opening (see Fig. 376).

The corrugated ribbon is stretched between the core ends so that it can vibrate back and forth as sound waves strike it. Connections are made to the ends of the ribbon.

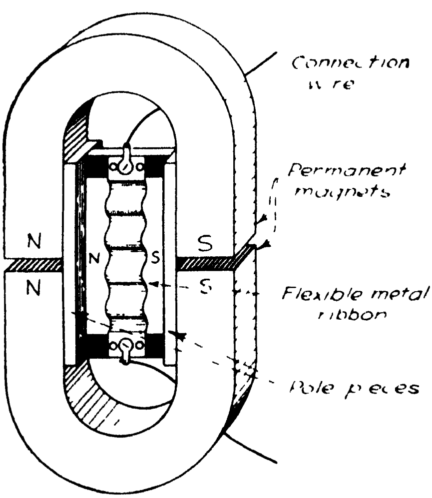


FIG. 376. The construction of the velocity microphone.

Circuit. As shown in the circuit in Fig. 377, the velocity microphone is connected directly to the primary of the microphone transformer. No battery is needed.

How it works. Sound waves cause the long duralumin ribbon to move back and forth. As you already know, when a wire or other conductor moves in a magnetic field, a voltage is generated in the wire. The movement of the duralumin ribbon as it follows the compressed and rarefied parts of the sound waves produces currents of varying strength in the primary winding of the microphone transformer; these currents induce voltages in the secondary and apply them to

the tube of the preamplifier circuit, the first stage of the speech amplifier.

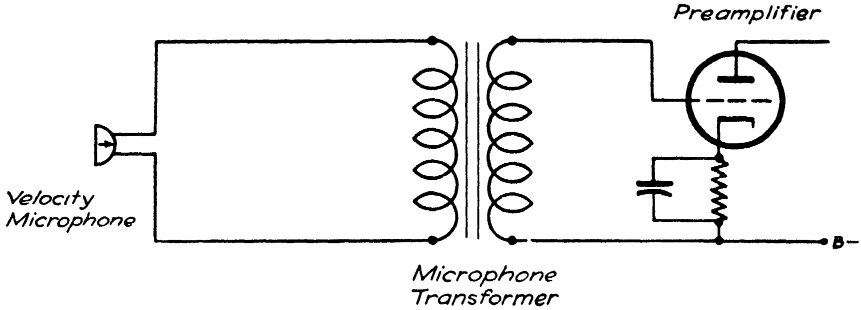


FIG. 377. The circuit for the velocity microphone.

Questions

1. Is the velocity microphone a rugged instrument?
2. Compare its cost with that of the other types.
3. Is it directional?
4. How much amplification is needed?
5. Do you need to connect a battery in the circuit?
6. Compare this microphone's tone quality with that of the other microphones.
7. Compare the action of duralumin ribbon with that of an electric generator.

PART 4: HOW TO BUILD A SIMPLE PUBLIC-ADDRESS SET

You can assemble your first simple public-address set from the circuit units you have already built. The preamplifier can use a 6J7 tube, the power amplifier a 6F6. Although this unit will provide only low power output, it is a good one to start with. You will later add to it until you have a powerful public-address set.

Start with a single-button carbon microphone. Besides this, the only new part you will need for this simple circuit is the microphone connection board.

The Board

Mount the parts for the microphone unit as shown in Fig. 378. One flashlight cell provides mike current.

Mount a jack at the left of the board to plug in the microphone. You will also need a two-circuit plug on the end of the microphone cord. The microphone cord is generally a shielded cable in which two inner wires are connected to the two buttons, and the outer braided shield is connected to the remaining wire. Use clips to hold the dry cell on the circuit board.

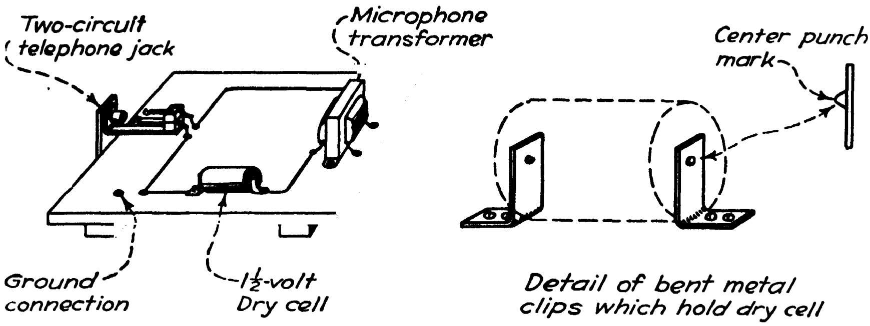


FIG. 378. This is the single-button microphone board. On it is the telephone jack, the batteries, the meter, and the microphone input transformer.

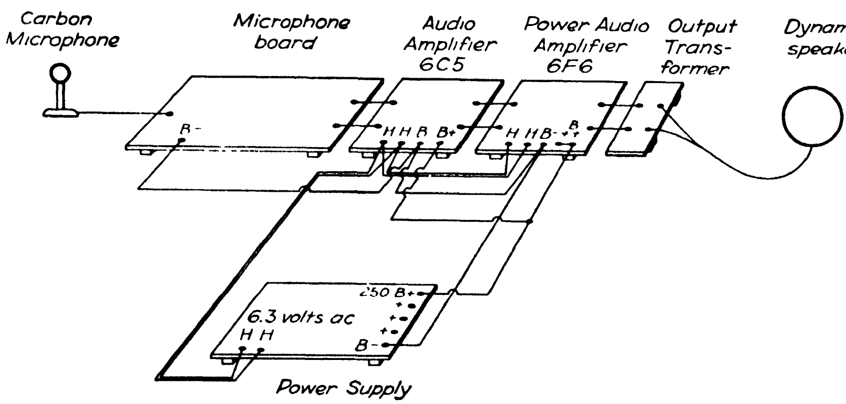


FIG. 379. A simple public-address set. Hook up these boards to make an excellent and simple set to use to get acquainted with the operation of a public-address set.

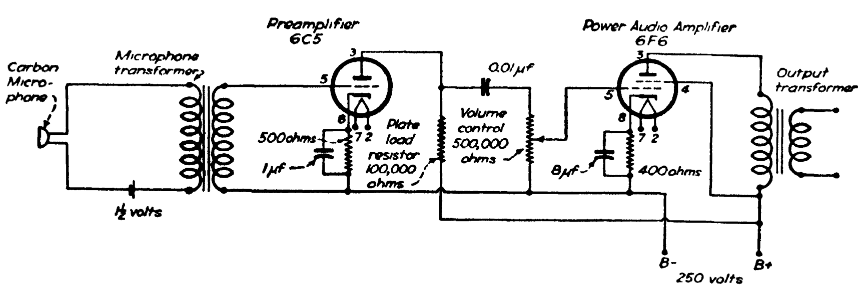


FIG. 380. The circuit for the simple public-address set.

The Transformer

Choose a transformer so that the input, or primary, winding has the same resistance as the low-resistance microphone, and the secondary has a high resistance to match the impedance of the grid circuit.

How to Hook Up the Equipment

Step 1. Connect the mike board, the two amplifier units, the heater supply, and the speaker, as shown in the block diagram of Figs. 379 and 380.

Step 2. Turn on the power supply.

How to Operate the Public-address Set

Step 1. Plug the microphone into the jack on the microphone board. Place a single dry cell in the clips, and the set is ready to operate. (Remove the battery or pull out the microphone plug to avoid running down the battery when the set is not being used.)

Step 2. Speak into the microphone, and note the loudness and quality of your voice as it comes out of the speaker.

Find the best position from which to speak into the mike. Speak directly into it with the same loudness, first with the mike near to your mouth, then with it farther away. Also try speaking with the mike at the side of your mouth, so that you speak past it.

Questions

1. How can you tell how much resistance to put in the microphone-transformer primary?
2. What determines the resistance of the secondary of this transformer?

PART 5: HOW TO BUILD A MORE POWERFUL PUBLIC-ADDRESS AMPLIFIER

After you have learned to use the simple low-powered public-address set and are acquainted with its principles and operation, you will enjoy adding the many improvements that will give it more power and better tone quality.

Below are some of the changes in the circuit that you can make; observe the effect of different tubes and controls on the operation and output of the set.

Improvement 1

Add more preamplification. This is the same circuit that you used in the first public-address set, but a 6J7 preamplifier is added

to boost the gain of the set. *Gain* is a word used to express the amount of amplification produced by a circuit. The output of the 6J7 amplifier circuit is further built up by the addition of the 6C5 amplifier circuit to operate the power amplifier and give you a higher level of sound from your set.

This hookup is shown in Figs. 381 and 382. This 6C5 set should have a volume control in its input circuit.

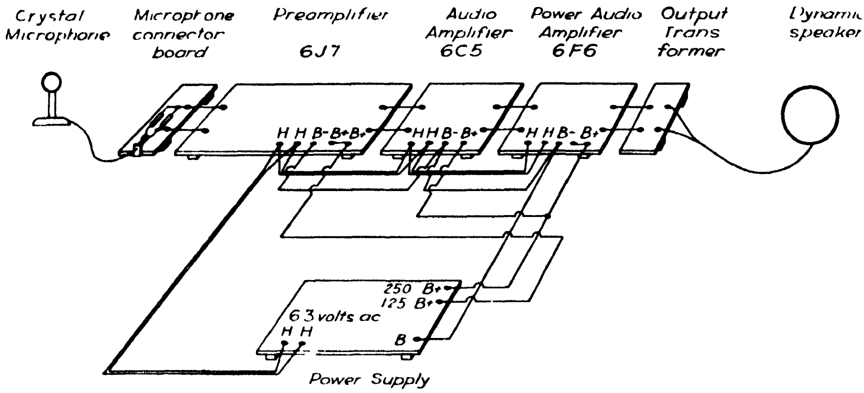


FIG. 381. A more powerful public-address set may be had when you hook up the set boards shown in this diagram.

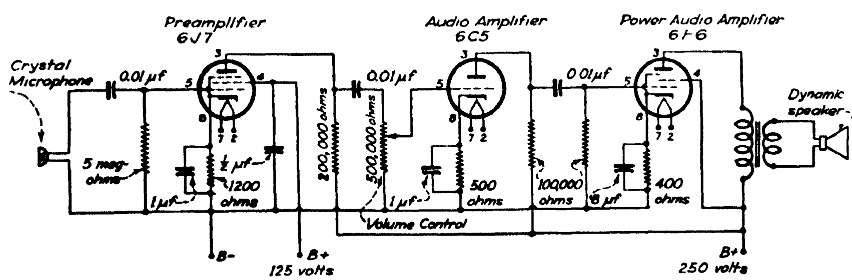


FIG. 382. The circuit for the more powerful public-address set.

What is the effect? Operate this new set, and note the effect on the volume and quality of the sound. Use the volume control to vary the sound volume.

Improvement 2

Use a more powerful final amplifier. Replace the 6F6 power-amplifier circuit by a push-pull 6F6 amplifier circuit (see Figs. 383 and 384. This is the same push-pull circuit that you used in

Chapter 16, "Basic Receiving Circuits Using Alternating-current Tubes").

What is the effect? This circuit will give you a much greater volume of sound than the other sets you have used. The quality is also improved. Such a circuit must be used when you want to cover a large auditorium or an outdoor meeting.

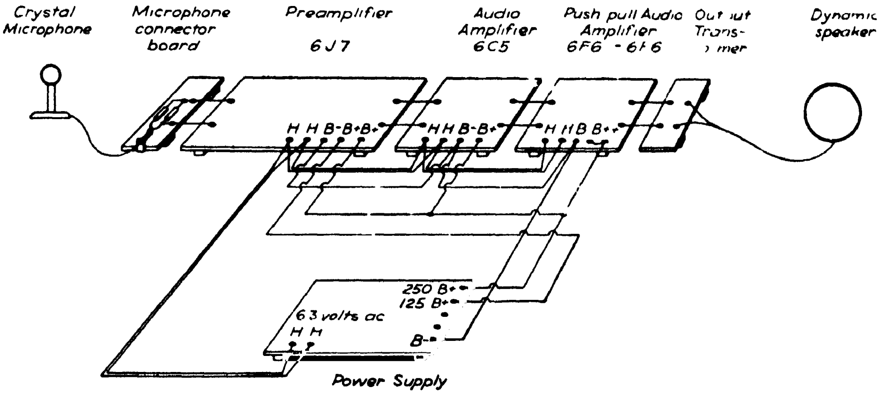


FIG. 383. Your public-address unit will have more power when you add the 6F6 push-pull power audio amplifier.

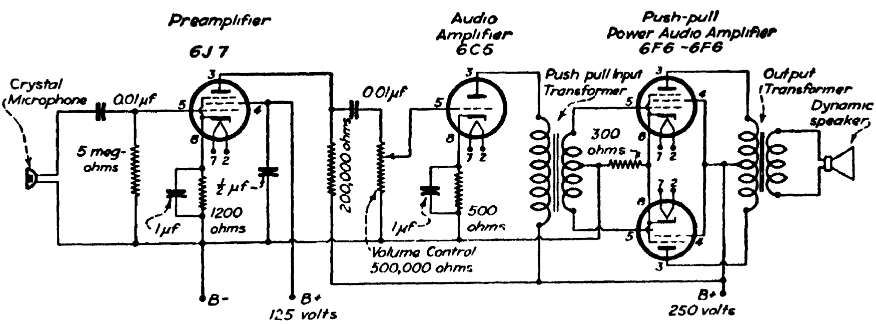


FIG. 384. The circuit for the push-pull, public-address set.

PART 6: HOW TO ATTACH A RECORD PLAYER TO YOUR AMPLIFIER

What is a two-input preamplifier? A common circuit for public-address work has input jacks for either a microphone or a phonograph reproducer, or pickup. The pickup circuit, which in your experiment will be a crystal pickup, needs less amplification than does the microphone. So the output of the microphone is fed into the first amplifier, and the output of the pickup is fed into the second amplifier (see Fig. 385).

What is the purpose of the fader? The fader is simply a center-tapped potentiometer (500,000 ohms resistance on each side of the center tap) used to connect the 6C5 audio-amplifier circuit either to the output of the crystal pickup or of the crystal microphone. When you move the sliding contact toward *C*, the volume of sound from the crystal microphone is increased. Then by moving the sliding contact past *B* and toward *A*, you can hear the record being played on the turntable (see Figs. 385 and 387).

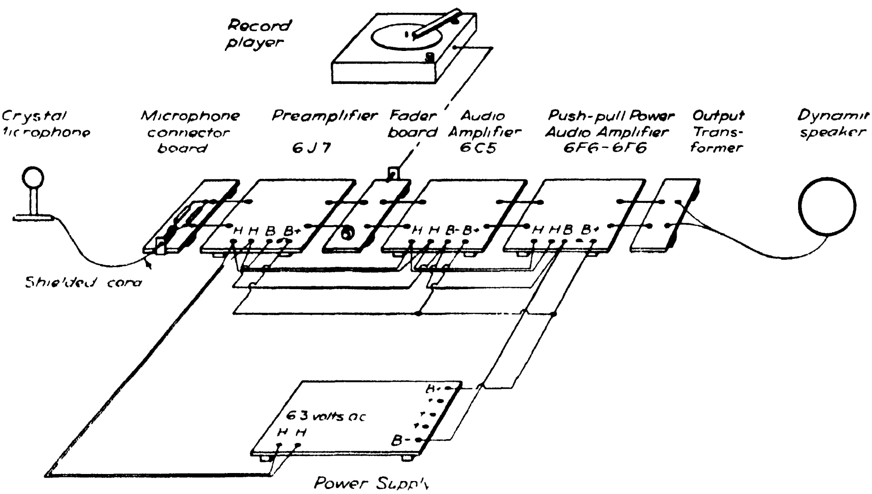


FIG. 385. Here is an amplifier that, by means of a two-input circuit, can be used to supply dance music as well as to make announcements. A fader resistor permits you to fade in either the microphone or the record player.

What is a phonograph pickup? The audio-amplifier circuits developed for radio use also make possible electrical recording of high quality. Recording equipment now produces very fine records of music. Many who love good music build up libraries of their favorite recordings.

These records can be enjoyed by playing them on an electrically driven turntable. You can build a separate unit to use with your public-address amplifier, or you can play back the records on a radio-phonograph combination instrument.

The record player consists of an electrically driven turntable and a pickup arm (see Fig. 386). The crystal pickup is popular because it has good tone and is fairly inexpensive.

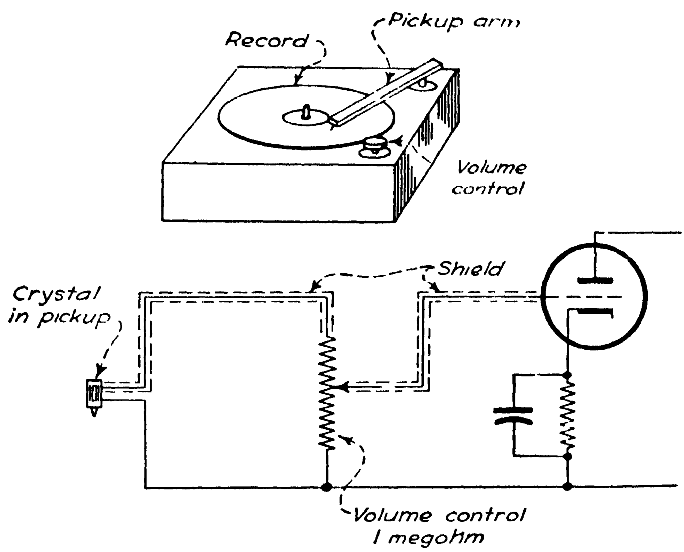


FIG. 386. The record player shown here is driven by an electric motor and has a crystal pickup arm. The volume control sets the input to the grid of the amplifier tubes.

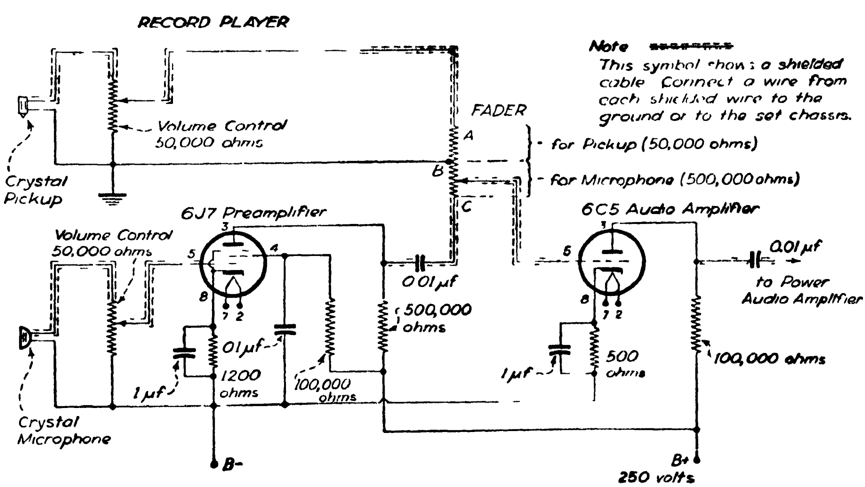


FIG. 387. The schematic circuit diagram of the two input parts of the public-address units shown in Fig. 385.

How to build and wire it. The pickup can be mounted in a suitable box, or the whole amplifier and pickup can be built together. A volume-control resistor comes with the pickup and is wired as shown in Fig. 386. Wire the complete circuit as shown in Fig. 387. Note the connection to the fader resistor. Note that the grid wire on the preamplifier board and several other wires in the circuit are shielded. This is done to prevent the pickup of hum by these wires. Hum picked up by the preamplifier is amplified and, unless prevented by the shielding, can become very objectionable.

The shield is connected to B minus by a wire soldered to the metal-braid shielding. Shield only the grid leads when your set is built on a metal chassis. Use the shielding shown in Fig. 387 when you use breadboard construction.

How to operate the amplifier. The connection of the various unit boards is the same as the connection for amplifiers described earlier in this chapter. The fader, the new part of this circuit, is simply turned one way to fade in the microphone or the other way to fade out the microphone and fade in the record player.

Why it works. The needle holder on the phonograph pickup arm is connected to the crystal. As the needle follows the grooves cut in the record, it moves from side to side.

This motion causes a twisting of the piece of Rochelle-salt crystal. This twisting action sets up an alternating current in the metal plates mounted on the crystal surfaces. (The action of crystals is further explained in Chapter 20, "Power Oscillators and Amplifier Circuits.")

The output of the crystal is fed to the grid circuit of the amplifier in the public-address set. The action of the volume control has already been explained.

You can also use this pickup with the amplifier in your home radio set. If you want to do this, find the circuit of the set from a radio technician or from Rider's *Manual*, and then get the advice or help of your instructor or the technician.

You can install a closed-circuit jack at the proper point in the circuit so that you can plug in the pickup whenever you wish.

Questions

1. Describe some ways for increasing the preamplification of your public-address set.

2. How can you change your set so that it will be a two-input amplifier?
3. List some advantages of crystal pickups.

PART 7: HOW THE PHASE-INVERTER AUDIO AMPLIFIER OPERATES

Transformers used for coupling audio-amplifier circuits can be responsible for frequency distortion. This effect occurs because the winding of a transformer, which is a form of choke coil, has increasing reactance to currents of higher frequency. Therefore, the coupling transformer, with thousands of turns of wire on an iron core, may cause the amplifier to amplify higher frequency tones much less than it does the medium-frequency tones. Distortion can also occur at the low frequencies if the transformer is not properly designed.

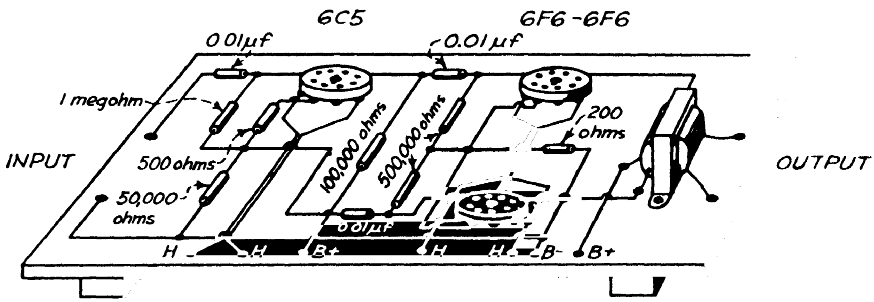


FIG. 388. This is the layout of the parts for the phase-inverter circuit.

If music or speech is to sound right, all frequencies from very low tones to very high tones should be produced at the same relative strength as the original tones. A high-fidelity circuit will do this. But with an ordinary coupling transformer, both high and low tones are cut down in strength, and the quality of the music suffers. Transformers that compensate for this distortion are expensive. It is easier and much cheaper to get the same result by means of a resistance-coupled circuit.

You have already studied the single-tube resistance-coupled audio amplifier. The resistance-coupled amplifier that does the work of a push-pull circuit is called a *phase inverter*. A network of resistors is used for coupling in place the more expensive push-pull audio-input transformer.

How to build and wire the circuit. Lay out the parts for this circuit as shown in Fig. 388. Wire the parts as shown in Fig. 389.

Why it works. You learned, when you studied the push-pull power amplifier, that the voltage on the grid of each amplifier tube must be 180 degrees out of phase with the other. When electrons are forced on the grid of tube 1, they must be pulled off the grid of tube 2. When you used a transformer, the surges induced in its secondary at one instant forced electrons on to one tube grid and

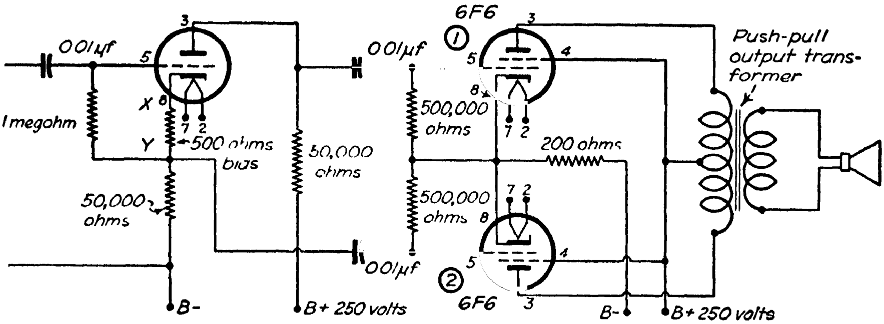


FIG. 389. This is the schematic diagram of the phase-inverter circuit.

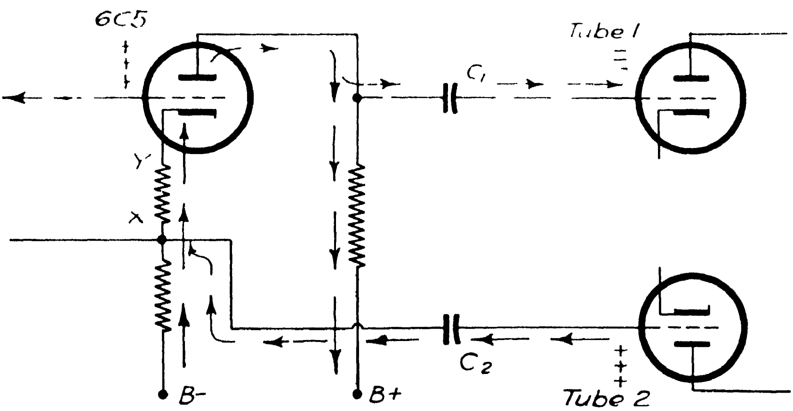


FIG. 390. When the grid of the 6C5 becomes positive, the resulting surge of electrons through the circuit makes the grid of tube 1 go negative and that of tube 2 go positive.

at the same instant pulled them off the other. The two grids were 180 degrees out of phase. Now note how this is done without a transformer in the phase-inverter circuit.

The first tube, the 6C5 (see Fig. 390), operates as a straight resistance-coupled audio amplifier. As electrons surge through the plate circuit, they are driven onto condenser C_1 and onto the grid of tube 1. This part of the circuit is simple and easy to under-

stand. But how can we get electrons onto C_2 and the grid of tube 2 so that they are 180 degrees out of phase with those on tube 1?

How is voltage applied to grid 2? By a clever use of the voltage drop across the bias resistor XY, electrons are forced onto condenser C_2 and onto the grid of tube 2, 180 degrees out of phase with the electrons on tube 1 (see Fig. 391). Follow a surge through this circuit to grasp the way it operates. Start with a signal on the grid of the 6C5 which causes the grid's plate current to become stronger.

The current that flows through the plate circuit of the 6C5 also flows through the cathode resistor. When a signal causes the cur-

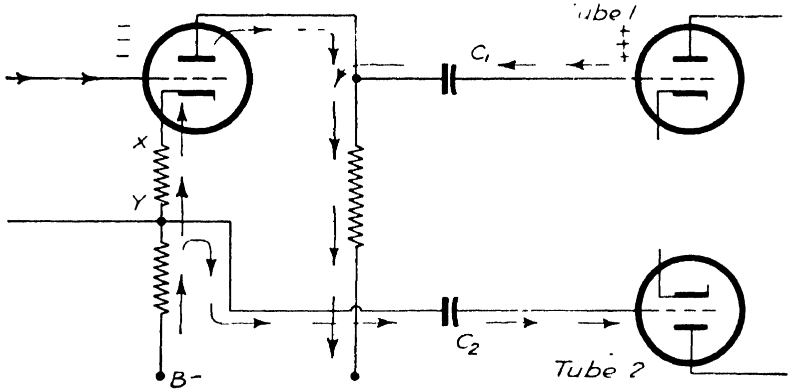


FIG. 391. When the surge on the grid of the 6C5 dies out and the grid again becomes negative, the charge on the grids of tubes 1 and 2 is reversed.

rent to increase, there is a difference of electron pressure (voltage) between X and Y at the ends of the cathode resistor. The electron pressure at Y is now lower than at X. Thus at the instant that the electron pressure on C_1 increases, the electron pressure on C_2 decreases.

Now, when the signal on the 6C5 grid makes it negative, *less* current flows through the tube (see Fig. 391). The greater pressure from B minus now forces electrons on C_2, but since less plate current flows through the 6C5 tube, the pressure of electrons on C_1 is reduced. Thus you see that by this scheme the pressure of electrons on C_1 and C_2 is maintained 180 degrees out of phase.

Questions

1. What is meant by the term *phase inverter?*
2. Explain how a phase inverter operates.

What is a universal output transformer? There are many cases where the voice-coil impedance of your speaker will not match the impedance of the output-transformer secondary on your set. Although such a combination will play, the power or loudness of the music is reduced, and the quality may suffer.

By installing a universal output transformer that has a tapped secondary, you can find a connection which will match the impedances and will give satisfactory music.

Examine the universal output transformer. This transformer is the same as an ordinary output transformer except that the secondary winding is tapped (see Fig. 309 in Chapter 16, "Basic Receiving Circuits Using Alternating-current Tubes").

By connecting the speaker voice coil between the common terminal and one of the other taps, you can easily find the best impedance match.

PART 8: HOW TO CONNECT DISTANT LOUDSPEAKERS

You often wish to place your microphone in a convenient position for the person who is speaking. Conceal the amplifier and

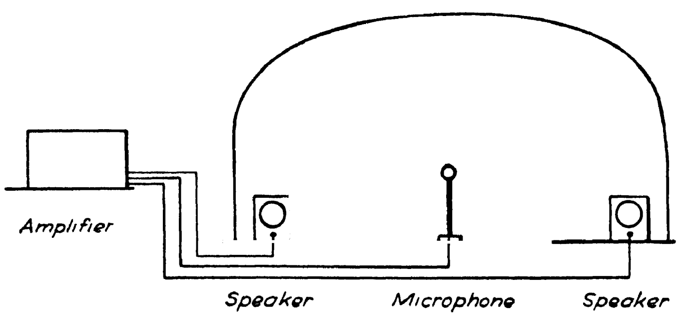


FIG. 392. This is a typical setup for a public-address set on a stage or on a platform.

place the loudspeakers in a position where the sound they deliver will cover a fairly large room (see Fig. 392).

The connecting wires between the concealed amplifier and the loudspeakers can introduce enough loss to affect the volume of the sound; you can run the loudspeaker cables about 75 feet with relatively little loss (see Fig. 393). Connect the wire of your set to the distant loudspeaker with the ordinary rubber-covered parallel-pair wire used for extension cords to floor lamps or other appli-

ances. The universal output transformer should be located at the amplifier.

When the speakers are over 75 feet from the amplifier, you should connect a 500-ohm line to the 500-ohm tap of the output transformer on the amplifier. You will also need a second transformer at the speaker (see Fig. 394).

How are two speakers installed? When you wish to install two speakers, one on each side of a room or a stage, connect the voice

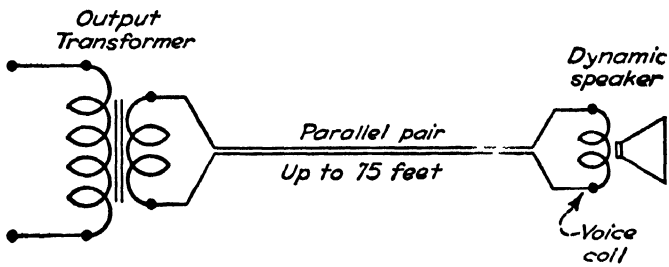


FIG. 393. Connect a parallel pair (extension-cord wire) between the public-address amplifier and the distant speaker as shown here. If the pair is too long, both volume and quality will suffer.

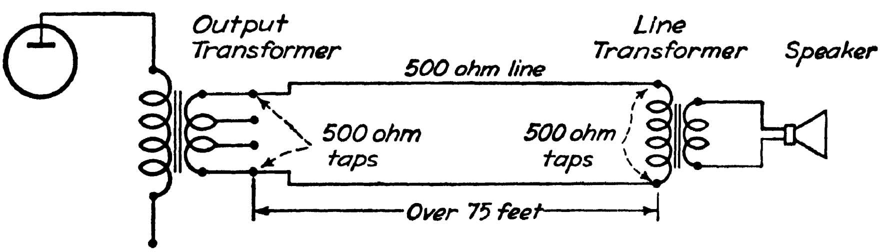


FIG. 394. You will need a matching transformer at the set and at the speaker when the speaker is over about 75 feet from the amplifier.

coils in series (see Fig. 395). This increases the total resistance of the two voice coils when they are connected together. It also gives a more even distribution of power output from the two speakers.

To phase the two speakers so that the cones move in the same direction at the same time, try reversing the connections to the voice coil of one speaker to see whether performance is improved. You can reverse the leads to the primary of the matching transformers at the speaker and have the same result.

What is the position of microphones and speakers? You have heard a public-address set build up in loudness and then break into a squeal while being adjusted when first put into operation. This squeal is caused by sound from the speakers feeding into the

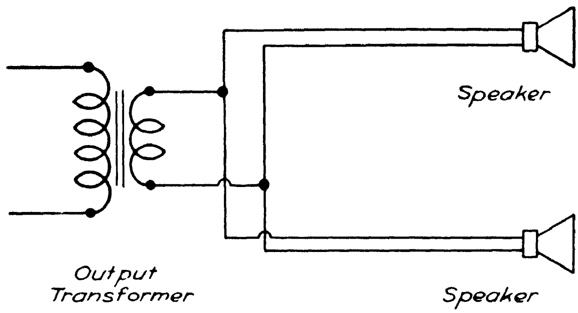


Fig. 395. Connect two speakers in parallel as shown here. Try reversing the leads to one speaker to see if it will change the quality of music produced by the two speakers.

microphone and back into the amplifier. It rapidly builds up to a squeal, or howl. Avoid this feedback by setting the microphone farther back on the stage than the speakers (see Fig. 396).

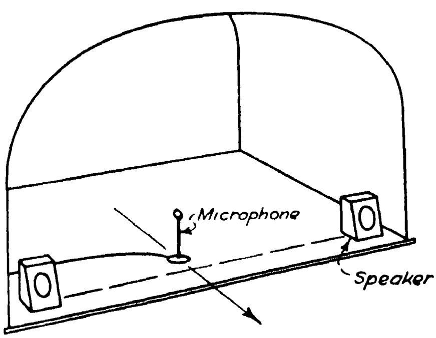


Fig. 396. When a microphone and speakers are set up, the microphone must be placed a few feet back of the speakers. If too far forward an unpleasant howl will grow up because the sound from the speakers feeds back through the set and rapidly builds up.

Sound may also rebound from a hard wall or window surface and, by reflection, cause a similar howl. Sometimes by turning the speaker or the microphone in a different direction, reflections can be reduced or eliminated.

When the volume is set too high, the poor acoustic properties of a room are brought out. Reduce the volume and note the improvement.

Adjust the tone control to find a best combination of volume and tone. Too much sound volume can make it almost impossible to understand a speaker. Stress the bass too much, and the result is also bad; it tends to muffle the voice.

PART 9: HOW TO BUILD AN INTEROFFICE INTERCOMMUNICATOR CIRCUIT

A busy executive needs a call system so that he can immediately talk with any of his employees. Go into a huge wholesale warehouse, and ask the clerk for a piece of equipment. He will find its number in a catalogue, flip a switch on a small amplifier, and call a man in the warehouse, which may be 100 yards away. This man may be 50 feet from the small speaker hung in the warehouse, but he answers from where he stands. The two men can quickly exchange the desired information.

This "intercom" system is widely used in offices so that a manager can immediately speak to anyone in the office. When the system is set up in a home, the housewife, merely by flipping

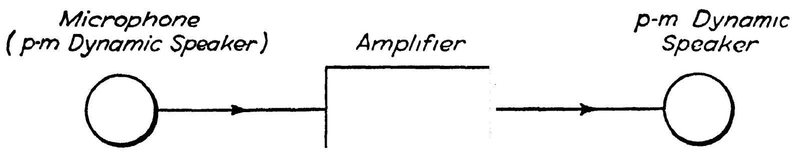


FIG. 397. This is a one-way interoffice communicator set.

a switch, can relay phone calls to the basement, upstairs, out to the garage, down to the rumpus room, or into the yard. An ingenious radioman can find dozens of similar applications for such a set.

An intercom set has a simple circuit. It is a two- or three-tube audio amplifier which uses a permanent-magnet (p-m) speaker for the microphone and a similar speaker for the output (see Fig. 397). This is a regular *one-way* public-address unit. But to be able to talk back, as did the man in the warehouse, some special arrangement must be made. The simplest way to do this is to set up a second unit working *from* the warehouse *to* the office (see Fig. 398).

This is sometimes done in expensive sets. A two-way set has the advantage of being always in operation and needing no switching between conversations. But it requires two complete amplifiers and four speakers. (Two of the permanent-magnet dynamic speakers are used as microphones.)

The more common form uses one amplifier and two speakers with a double-pole double-throw switch which reverses the two

speaker connections (see Fig. 399). You can then talk into one speaker and use it as a microphone, while the other is used as a regular speaker. Then when you throw the switch, the speaker

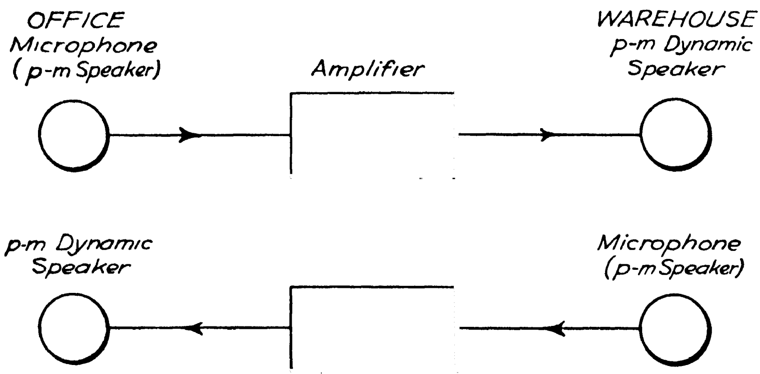


FIG. 398. You can make a two-way interoffice set either by using two separate circuits as shown here or by a switching arrangement as shown in Fig. 399.

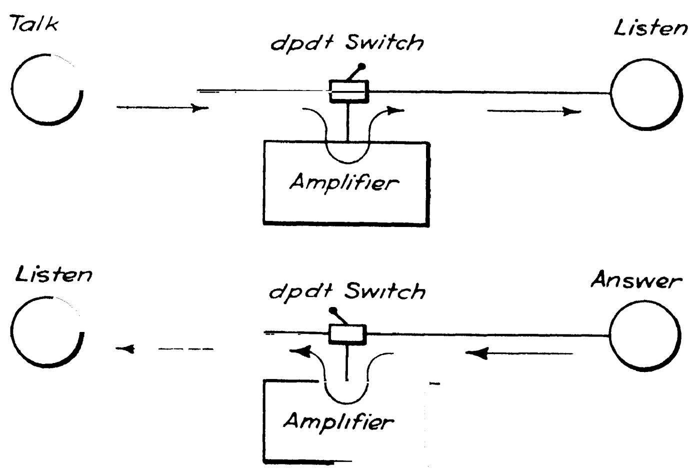


FIG. 399. This is a switching arrangement that permits you to use one amplifier and two permanent-magnet speakers for an interoffice amplifier unit. The switch permits you to talk in either direction.

at the other end is used as a mike and your speaker talks to you. A unit of this type will be described.

How to Build and Wire the Intercommunicator Set

Chassis. Build the communicator set on a $1\frac{1}{2} \times 7 \times 9$ metal chassis.

Position of parts. Since feedback is always a problem in audio circuits, you will have to experiment to find the best position of the tubes and parts before mounting them permanently. The double-pole double-throw (dpdt) talk-listen switch is a special rotary switch with a spring return. You press it down to talk. When you release the pressure, the spring returns the switch to the listen position. The other parts of the circuit are standard.

Feedback occurs when a strong magnetic field in one part of a circuit cuts across other wires of the circuit and induces voltages in them. The strongest fields in this set will be around the power transformer, the power choke, and the output transformer. You normally have little trouble with hum and feedback when you work with breadboard sets, for several reasons: the parts are relatively far apart, so that there is little feedback; the different circuits, and particularly the power-supply circuit, are on different boards; and the boards are made of wood.

In the set you are now building, the power supply is on the same metal chassis and the parts are close together. Currents induced in the metal chassis cause part of the hum. Induction between set wiring also causes hum and feedback. The wires most sensitive to feedback are those in the grid circuits. Any induced voltage picked up by the wires of the 6J6 grid circuit will be amplified by both tubes.

Hum reduction. Hum from the power supply is hard to eliminate. You can avoid much of this hum by placing the power supply on one corner of the chassis and the input transformer and wires on the other. Placing the grid-circuit wires at right angles to plate circuit wires may also help. Shielded wire is sometimes used in the grid circuits. The metal shield around the wire is grounded to the chassis.

Wiring to the talk-listen switch must also be carefully placed. Shielded cable on the wires is shown in the schematic diagram by dotted lines (see Fig. 400). Ground the outside shielding to the chassis.

The selector switch is wired so that you can easily switch to any of the different speakers from the master amplifier unit.

How to Operate It

Turn on the set. When the tubes have heated, you will hear a low hum. This hum in the speaker is a handy way to tell that

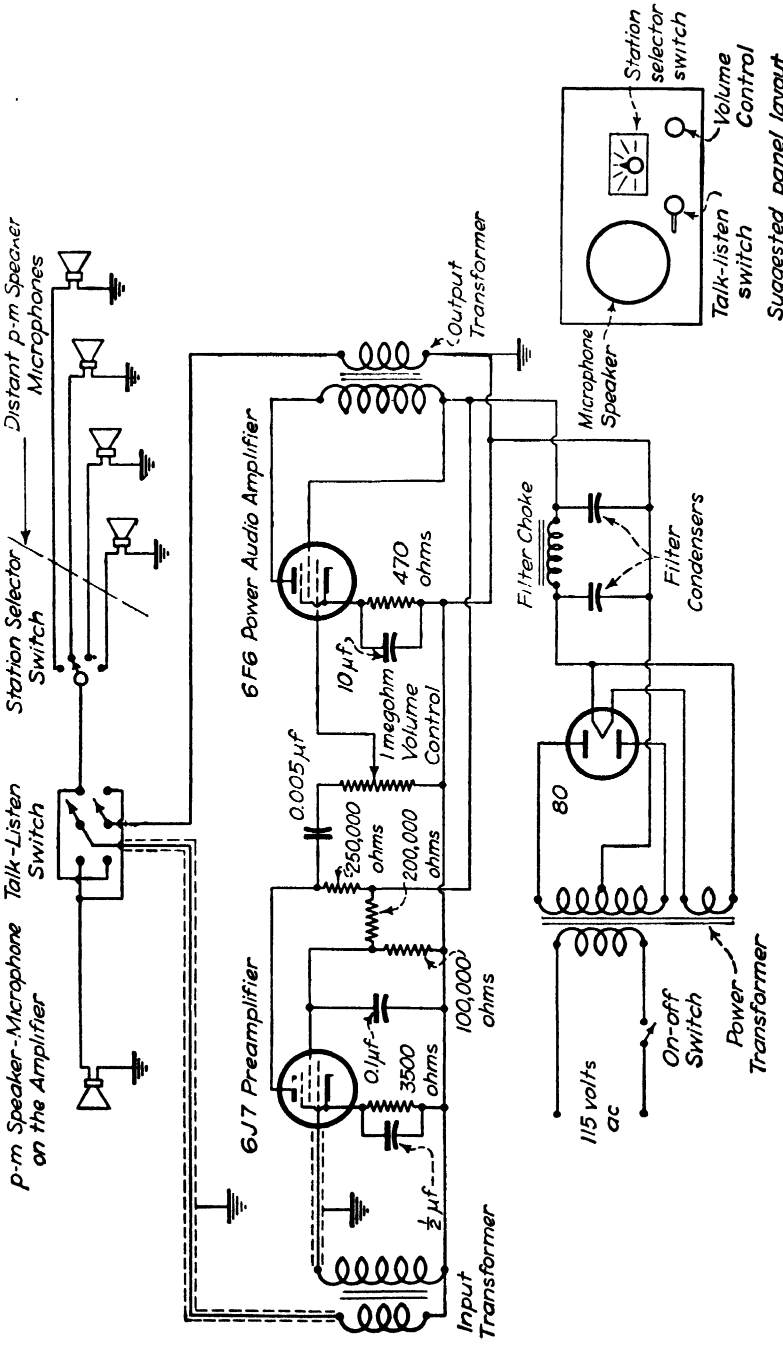


FIG. 400. This is the complete schematic diagram of an intercommunicator unit complete with power supply.

the set is in operation. As wired, this set lets you hear in the room to which the set is switched any sounds from the speaker.

These sets are very sensitive. You can readily talk to a person anywhere in a large room. You can hear birds many feet from open windows. You can call an instructor or a mechanic in a large shop.

By switching a home set, the housewife in the kitchen can call a person sleeping late, can call a child playing in the yard. She can speak to a caller at the front door. She can save steps by switching to a speaker on the second floor; then, by again turning the knob, she can talk to someone in the basement.

To talk you must press down the talk-listen switch lever. Release the switch lever and you can hear the answer. You can also wire the set so that you press to listen.

Why It Works

When you speak at the master unit, the sound waves caused by your voice move the cone of the permanent-magnet speaker. As the wires of the voice coil move through the powerful field of the permanent magnet of the speaker, a voltage is generated in them. The speaker thus acts like a dynamic microphone.

These voltages are amplified, and the speaker to which the set is switched produces the sound. When you press down the double-pole double-throw switch, you change the connections so that the distant speaker, which is connected to the grid of the 6J7, acts as the mike, while the speaker on the master unit acts as a speaker.

Reason for Hum

Hum comes from the power-supply wiring. The changing fields around the power transformer and the wires to the rectifier tube and filter reach the wires of the grid circuits of the amplifier tubes and create some hum. Metal shield plates bolted to the underside of the chassis help shield out some of the hum. A low hum is not objectionable, and it tells you when the set is turned on.

Questions

1. What is the cause of feedback?
2. How can it be avoided?
3. What causes the hum in a talk-back set, and how can it be avoided?

Tone control. Some people prefer to hear music in which the bass tones are prominent. Others prefer to stress the treble tones. You can easily install a control on your receiving set or public-address system so that the tone can be changed at will.

A simple tone control is made by connecting a 0.005-microfarad condenser and 500,000-ohm resistor in series, as shown in Fig. 401, and connecting them across the output circuit of the first audio amplifier.

Why it works. Because the capacity of this condenser is small, it will have a high impedance to low audio frequencies but will

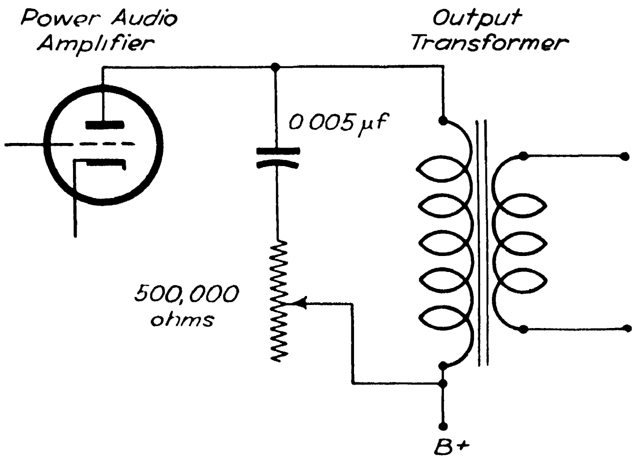


FIG. 401. This tone-control circuit may be added to the output circuit of a public-address unit or to an audio amplifier. With it you can set the amount of bass or treble in the music.

have a low impedance to high frequencies. Therefore, the part of the current which carries the high frequencies will be by-passed around the primary of the audio transformer. The remaining current will flow through the primary of the audio transformer. In this way the higher frequencies are by-passed and the lower frequency tones are made to predominate. By adjusting the resistor, the amount of high-frequency signal that is removed can be controlled.

PART 10: THE EXPLANATION OF POWER-AMPLIFIER BIAS

There are several ways to bias an amplifier so that it will deliver music of excellent quality, give more efficient amplification, or deliver more power to the speaker.

Several classes of audio amplifiers are used. These are class A, class AB, and class B. The latter two are mostly used in powerful public-address equipment. Class C amplifiers, still more efficient, are used in transmitters and are described in Chapter 20, "Power Oscillators and Amplifier Circuits." The difference between these classes of amplification is the strength of the signal and the amount of negative grid bias used for each. The bias-resistor values given for the amplifiers described earlier in this chapter were intended to give good reception as class A amplifiers.

The Class A Amplifier

Why class A amplification is used. The class A amplifier is used because it produces music of excellent quality. Generally, the tube is a triode or pentode. The class A amplifier has low power output and low efficiency. For higher power output class AB or class B amplification is used. The class A amplifier is used with either a single-tube or a push-pull circuit.

The class A amplifier is biased so that the grid always remains negative and no grid current flows. The plate-current wave shape is the same as that of the grid wave. This produces clear, good music.

This amplifier is designed so that the voltage swing it sets up on the grid of the class A final audio-amplifier stage does not exceed a certain value. An example will make this clear. Suppose you wish to use a 6F6 amplifier tube in the final stage of a receiver. In the Selected Tube List, pages 668 669, you find that for a plate voltage of 250 volts you must have negative bias of 16.5 volts on the 6F6 tube.

The preceding audio stage is designed so that its output will cause the grid to swing not more than 16.5 volts. The grid then will remain negative. If the grid swing were *over* 16.5 volts, the grid would become positive on the peaks and, on the negative peaks, the grid would become so negative that the plate current would cease to flow. (Assume that cutoff for this tube is 16.5 volts.)

If the grid is allowed to become positive, it will attract electrons and distortion will result. Distortion will also be produced when the plate-current flow is shut off during the negative part of the cycle. In a class A amplifier there is always plate current flowing.

Class A amplification is widely used in broadcast work where a high quality of music is of first importance.

Why a class A amplifier produces clear music. Perhaps you have wondered why you ran the grid-voltage-plate-current curve when you studied alternating-current tubes. You were told at

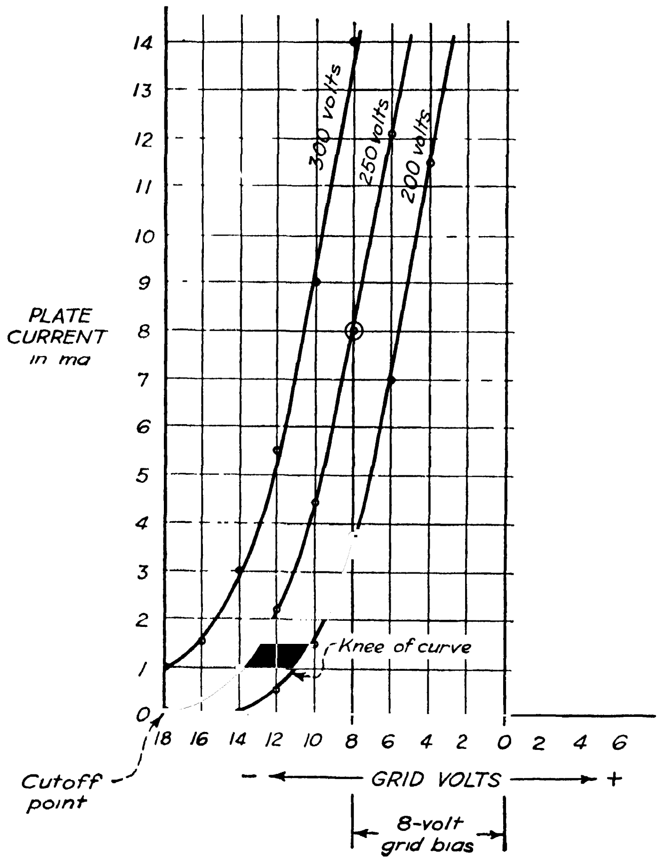


FIG. 402. This is the grid-voltage plate-current curve of the 6C5 tube you ran in Chapter 15, "Alternating-current Receiving Tubes," to show the control the grid had over the plate current.

that time that you would later use the information you gathered in running this curve.

Examine the curve for the 6C5 tube again (see Fig. 402). Note that the lower end is curved near the base line and then the curve rises rapidly and is a straight slope. What does this curve mean?

Start with no electrons on the grid. This curve shows that

about 30 milliamperes of plate current flows. Then, as you make the grid negative, less plate current will flow. At 4 volts negative, 18 milliamperes flow; at 6 volts negative, 12 milliamperes flow—a 4-milliampere decrease. The curve shows the same decrease at 8 volts negative and nearly the same decrease at 10 volts negative. The *straight* part of the curve means a steady rate of increase of plate current with every time you make the grid 1 volt more positive.

However, when you make the grid 12 volts negative, the line curves or begins to flatten out. This is the knee of the curve.

Where before, on the straight part of the curve, the plate current cut down 4 milliamperes for each volt the grid became more negative, now there is *less* decrease of current for each volt making the grid more negative. Finally, the plate current stops at 18 volts negative. This is the cutoff point. Making the grid more negative now has no further effect on the plate current. Note that this curve is made at a fixed plate voltage of 250 volts. A higher plate voltage will produce a curve in which the grid must be more negative for cutoff (see the 300-volt curve).

Bias for class A amplification. Suppose you use 250 volts on the plate of your amplifier tube. Mark the center of the straight part of the curve. This is the no signal point to which the tube must be biased for class A operation. Here the grid bias is 8 volts negative.

Now, when a 6-volt signal reaches the amplifier, it will make the grid 6 volts positive and 6 volts negative if there is no bias. But because of the negative grid bias of 8 volts, the grid actually goes 6 volts negative plus 8 volts negative, or 14 volts negative, and 6 volts positive plus 8 volts negative, or 2 volts negative. With no signal, the grid is 8 volts negative. The rise and drop in grid voltage caused by a signal is above and below the minus-8-volts bias point. Note that there is the same increase and decrease in plate current, a condition which produces amplified but undistorted music and sound.

Now examine the curve for the 6F6-pentode power audio amplifier that you have been using for the last stage in your public-address amplifier (see Fig. 403). You can read this as you read the 6C5 curve. There are a few differences that you should note. One is that at 250 volts the grid bias should be 16.5 volts, over

twice the bias voltage for the 6C5. At this bias 35 milliamperes of plate current flows.

Another difference is that there is no knee to this curve. This is a characteristic of the pentode tube. It is caused by the other elements in the tube.

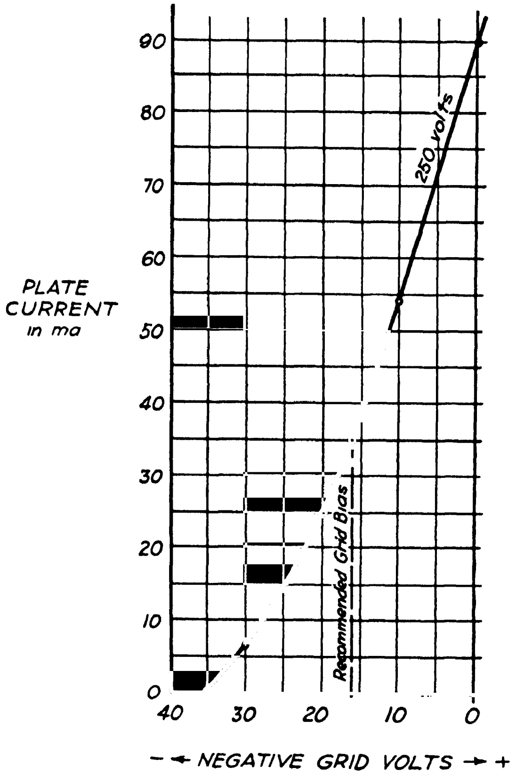


FIG. 403. This curve shows plate-current changes for the 6F6 pentode tube as the grid is made increasingly negative.

The slight curvature of this graph shows that there will be some distortion of the audio signal. If the curve were straight, there would be no distortion.

The 6F6 tube, with greater plate current flowing, makes possible greater power output than was possible with the 6C5 you used in earlier experiments. The greater power output of the 6F6 is made possible by its larger grid swing and the correspondingly greater changes in plate current.

The Class AB Amplifier

Other types of amplification. You may read about class A, class AB, or class B amplification. These classes are, as the letters indicate, biased somewhere between the classes explained above. Class AB is biased more than class A but less than class B.

Class C amplification is only used in radio-frequency power amplifiers. If used in audio circuits, it produces serious distortion. This trouble is avoided in the radio-frequency circuits because the tube there drives a tank circuit which eliminates the distortion.

Why class AB amplification is used. The low- or medium-power class A amplifier is only satisfactory for rooms of average size. When coverage of larger areas such as an auditorium, a picnic, or a ball game is desired, higher powered sets are selected. If they use class A amplification they will require special power tubes and heavy power-supply equipment. Both tubes and power supply are expensive. But by using a different class of amplifier, less expensive tubes and a lighter duty power supply can be used at a considerable saving in cost. The class AB and class B amplifiers are widely used for such service. They will produce louder sound with good efficiency. Class AB and class B amplifiers always use push-pull output circuits and power tubes designed to handle much current. The class AB circuit puts out about 50 per cent more power than does the class A circuit.

Tubes used for class AB amplification. The 2A3 and the 6A3 are two triode tubes that can be used for class AB amplifiers. Power pentodes such as the 6F6 and the 42 are also used. But beam power tubes such as the 6V6 and the 6L6 are designed especially for such service. They handle much power with good quality.

In the push-pull circuit, one tube operates during half the cycle and cools off during the other half while the other tube works. In this way, the full cycle of plate current flows half through each tube. Enough current flows to give a great deal of power at the speaker, and the tubes run cool. Here, higher plate voltages and higher current can be used, because each tube works only half the time.

Bias for class AB amplification. The grid bias is shown in a good tube chart. For two 6F6's in push-pull, with 375 volts on

the plate and 250 volts on the screen, the grid bias is negative 26 volts.

Questions

1. Give typical uses for each of the following types of amplifiers: A, AB, and B.
2. Compare the power output of the three classes of amplifiers.
3. Compare the efficiency of the three types of amplifiers.
4. Compare the grid bias on the three types.
5. In what circuits is class C amplification used?

CHAPTER 20

POWER OSCILLATORS AND AMPLIFIER CIRCUITS

The power oscillator is the heart of a transmitter. In it is generated the steady radio-frequency surging of electrons which, amplified and modulated and fed into an antenna, cause radio waves to be radiated through space.

You saw a crystal power oscillator when you visited the broadcasting station. It was described in the first chapter of this book. You also saw there the many tubes of the power-amplifier circuits of the broadcast transmitter.

You will study in this chapter several of the different basic power-oscillator circuits. Some are capable of generating radio-frequency surges that are powerful enough to be used for a low-power transmitter without amplification. You will also study different kinds of power amplifiers. These are used to strengthen the radio-frequency surges generated by the oscillator, so that the transmitted signal is many times more powerful. You will study the circuits of the Hartley oscillator, the tuned-plate tuned-grid self-excited oscillator, and the crystal oscillator.

What is an oscillator? An oscillator is a circuit which will generate a continuous electron surging, or oscillation, generally in a tuning or tank circuit consisting of a coil and a condenser.

Stability is an important characteristic of a transmitter. A stable transmitter operates at one frequency. If the transmitter is unstable, many things will cause its frequency to wander. You will notice the result of transmitter stability at your receiver. You can tune in a stable transmitter by turning to a certain number on the dial, and you will always find the same transmitting station at this number. If the transmitter were unstable, you would have to keep adjusting the dial on your receiver in order to keep the station tuned in.

What is a self-excited oscillator? This oscillator depends on coils and condensers to fix the frequency at which it operates. When the regenerative receiver you used in Chapter 11 was made to oscillate, it was behaving as a self-excited oscillator. Self-excited oscillators are rugged and easy to operate, but they are relatively hard to keep on frequency unless special precautions are observed, because the frequency is affected when you draw power from them. They are, however, used in many applications, such as in superheterodyne receivers or in portable military transmitters. They perform well when care is used in their design.

What is a crystal-controlled oscillator? This oscillator uses a quartz crystal to keep it accurately on the same frequency. It is widely used in amateur and commercial transmitters.

In this chapter you will learn about the following things:

Part 1: The Hartley Oscillator
Part 2: Construction of a Dummy Antenna
Part 3: The Absorption Type of Frequency Meter
Part 4: The Tuned-plate Tuned-grid Oscillator
Part 5: The Oscillating Quartz Crystal
Part 6: The Crystal-oscillator Circuit
Part 7: The Transmitter Power Supply
Part 8: The Radio-frequency Power Amplifier
Part 9: How to Neutralize the Power Amplifier
Part 10: The Frequency-doubler Circuit
Part 11: The Push-pull Final Power Amplifier

PART 1: THE HARTLEY OSCILLATOR

How to Build and Wire the Set

Arrangement of parts. Place a midget variable tuning condenser of 150 micromicrofarads maximum capacity at the left of the board (see Fig. 404). Wind a tank coil according to the directions under "How to Wind Oscillator Tank-circuit Coils" in this chapter.

Use a mica 0.00025-microfarad grid condenser and a carbon 50,000-ohm 5-watt grid leak.

The radio-frequency choke may be a standard 2½-millihenry receiver type of choke. Place the tube socket as shown in Fig. 404.

How to wire the set. The tuning circuit, which consists of the variable condenser and the coil, is called the *tank circuit* (see Fig. 405). The heaviest currents in the oscillator flow in the tank cir-

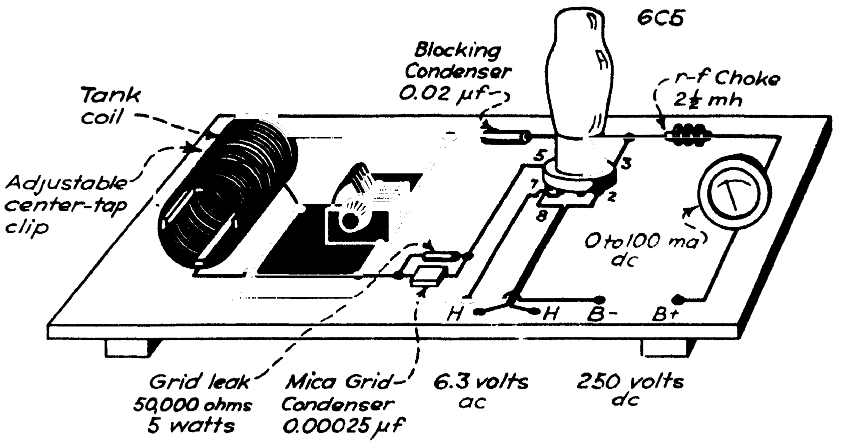


FIG. 404. The Hartley oscillator. This shows the layout of the parts on the baseboard. You may prefer to use a separate meter instead of mounting it on the baseboard.

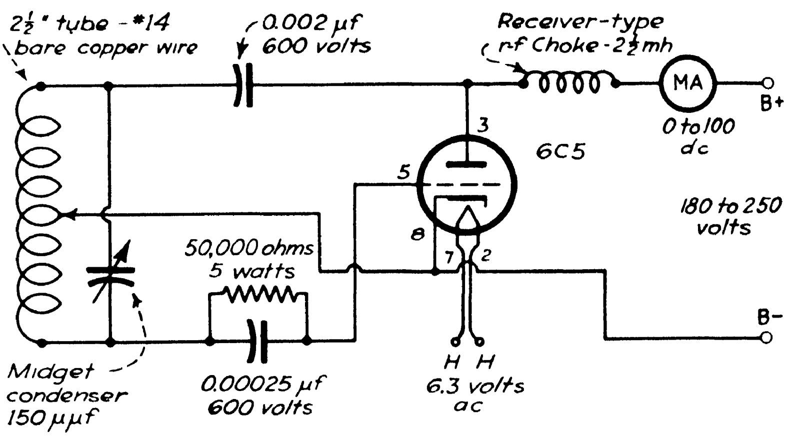


FIG. 405. This is the schematic wiring diagram of the Hartley oscillator. Note that this is a *shunt-feed* circuit. The B voltage is connected *across* the cathode and plate in shunt with the tank circuit.

cuit. Wind the tank with enameled wire about No. 14 in size. Wire the rest of the set with No. 18 enameled wire.

The Tank Circuit. Connect the ends of the tank coil to the tank tuning condenser, as shown in Fig. 404. Connect a clip to the cathode and B negative with a piece of flexible insulated wire about 6 inches long. This clip is moved along the coil to vary the grid excitation.

B-supply Connections. In this circuit the B supply is connected in shunt across the heater and plate, and so it is known as the shunt-fed type of circuit. A series type of circuit could be used. A comparison between the two will be found later in this chapter.

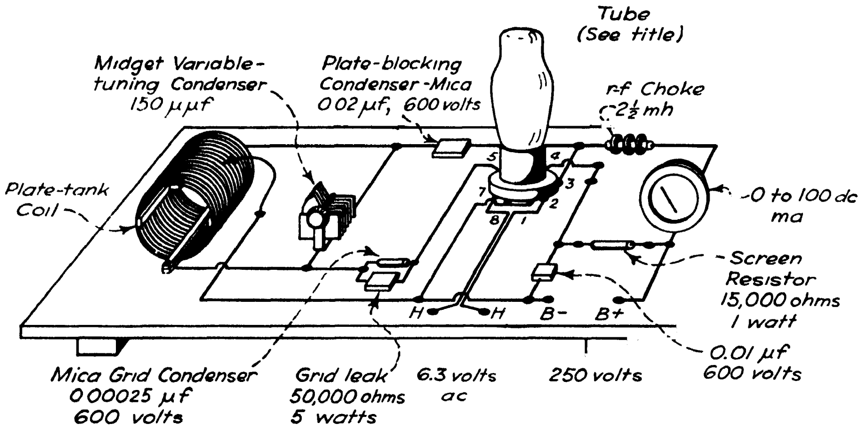


FIG. 406. This is the board layout for an experimental Hartley-oscillator circuit. You can plug in a 6C5, a 6V6, a 6F6, or a 6L6 tube without changing the circuit wiring or the tube socket.

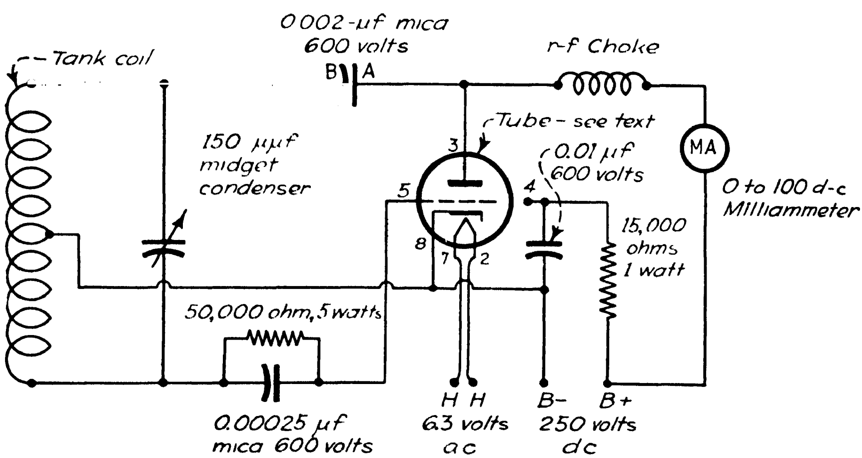


FIG. 407. By connecting the resistor and by-pass condenser to socket terminal 4, any one of several tubes can be plugged into this socket for oscillator experiments.

Connect a direct-current 0 to 100 milliammeter in the B-positive wire.

Connect 0.002-microfarad 600-volt mica blocking condenser, as shown in Fig. 405.

Tubes to Be Used. Many different types of tubes can be used in this oscillator circuit. You will use the 6C5 in your experiments. The 6C5 is sometimes used as an oscillator in receiving circuits, but the beam pentodes are better power oscillators in transmitter circuits. The 6F6, the 6V6, and the 6L6, all receiving tubes used for the power audio amplifier, are widely used by radio amateurs in the oscillator circuits of their transmitters (see Figs. 406 and 407 for a modified Hartley circuit useful for experimenting with other tubes as oscillators).

How to Wind the Oscillator Tank-circuit Coil

The coil form. Wind the coil on a 2-inch tapered wooden form 6 inches long.

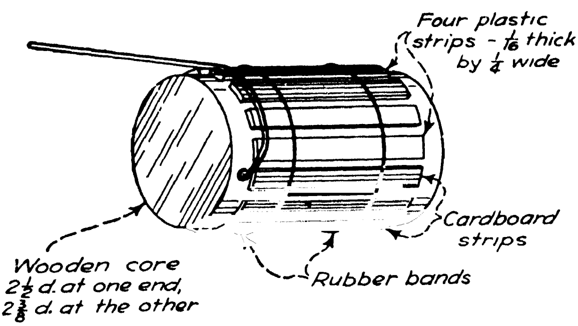


FIG. 408. Arrange four plastic strips on the wooden winding core as shown here. The cardboard strips keep the wire from sagging between the plastic strips.

The wooden form must be about $\frac{1}{8}$ inch smaller at one end than at the other, so that the finished coil can be slipped off the form (see Fig. 408). The wire will be cemented to four $\frac{1}{16}$-in. by $\frac{1}{4}$-in. plastic strips $2\frac{1}{2}$ inches long to form a spaced winding.

Cut enough $\frac{1}{16}$-in. by $\frac{3}{8}$-in. wide wooden strips to fit between the plastic strips to form the wire into a true circle. As you start the winding, hold the wooden strips in place between the four plastic strips with two rubber bands.

Be sure that the four plastic strips are parallel before you start the winding.

How to wind the coil. Wind the coil with No. 18 bare copper wire. Form the end of the wire into a loop (see Fig. 408). Fasten the loop in place at the end of one plastic strip with a wood screw. Unreel about 25 feet of wire. Fasten the loose end in a vise, or

attach it to some other solid object. Pull the wire tight, and wind the coil by rolling the form toward you. Space each turn as shown in Fig. 409 so that when completed the coil will have 28 turns and be $2\frac{1}{4}$ inches long.

Cut off the surplus wire, form a second loop, and fasten it in place with the second wood screw. Run airplane cement over the wires where they cross the plastic strips. When the cement is fully set, the wire will be held in place. Remove the screws, and slip the finished coil off the form.

Cut a second plastic strip $\frac{7}{16}$ inch wide, $\frac{1}{4}$ inch thick, and 3 inches long. Cement this strip to the strip opposite the loop in the ends of the coil. Drill two $\frac{1}{8}$-inch holes through the 3-inch

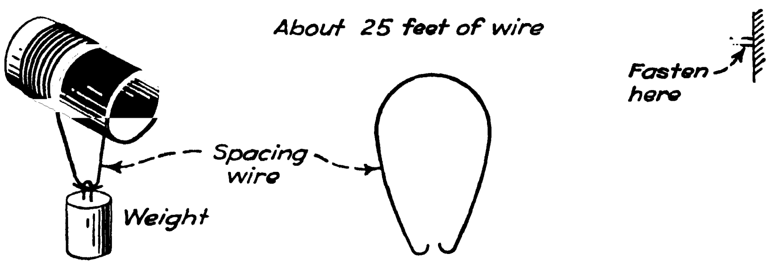


FIG. 409. This is an easy way to space-wind turns when winding a coil. Attach to the weight a loop of wire of the correct size to space the coil turns the desired distance. You may have to try several sizes of wire to get the correct spacing.

strip. Cement the loops at the ends of the coil over this hole, and your coil is ready for use.

Series and Parallel B-power Connection

Parallel feed. Parallel, or shunt, feed (see Fig. 405) is used in the experiments you will do with the Hartley circuit, because no plate voltage is on the tank circuit and there is little danger of receiving shocks as you adjust the circuit. But you may receive pin-point radio-frequency burns if you touch parts of the tank coil in either series or parallel-fed circuits.

Series feed. When series feed (see Fig. 410) is used, the direct-current voltage of the power supply is connected to the tank circuit, and there is danger of shocks when you are changing the position of the grid tap.

You can avoid shocks by turning off the B voltage with the switch in the B-negative wire on the power-supply board. You

need no radio-frequency choke in the plate lead when series feed is used.

Operating Precautions

Direct-current shocks. There is always danger of shocks in working with radio equipment. You can receive a shock if you touch any bare part of the B-positive wiring on oscillators and amplifiers. The direct-current shocks that you may receive on the low-powered oscillators and amplifiers described in this chapter as using 250 volts on the plate are strong enough to be unpleasant, but they are seldom dangerous to the average healthy individual.

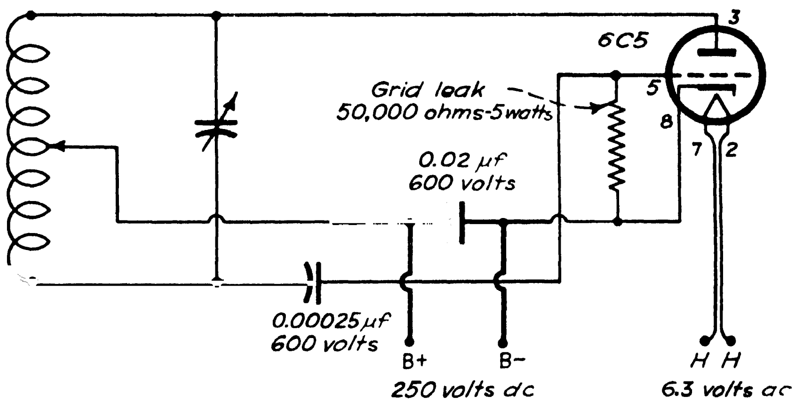


FIG. 410. This is the Hartley circuit with *series feed.* This means that the B voltage goes through the coil to reach the plate.

You should avoid touching any part of the plate circuit of this oscillator where there is a direct current.

In the shunt-feed Hartley circuit there is no direct current on the tank tuning circuit. The direct current is kept out of this circuit by the plate blocking condenser.

Radio-frequency burns. In the radio-frequency part of the shunt-feed Hartley oscillator, you will receive no direct-current shocks, but you may receive radio-frequency burns. You can draw tiny blue-white sparks to the point of a pencil from the stator plates of the tank condenser or from the plate end of the tank coil. If you accidentally touch a part of the tank circuit, you will feel no shock, but only the heat of the pin-point radio-frequency arc as it burns through your skin.

For safety, relatively low plate voltages are used in your experiments with oscillators and amplifiers, but no radioman worthy of the name permits himself to become careless. His warning is sudden and rude.

How to Operate the Oscillator

The adjustment and operation of an oscillator circuit is simple and follows a definite procedure which is similar for many different circuits. While learning this procedure, you will find it easy to get the set in operation if you follow a few well-defined steps.

Step 1. Attach the power-supply leads to the oscillator. Connect the wires for the heater current to the heater terminals on the oscillator board.

Now attach the B-minus and the B-plus wires.

Set the B-minus switch on the power supply to the *off* position.

Turn on the power supply, and as soon as the tube cathode has heated, the oscillator is ready to operate.

This circuit will oscillate well over a considerable range of plate voltages. Start with 250 volts on the plate.

Step 2. Throw *on* the B-minus switch. Check for oscillation as you turn the tuning condenser.

Is the circuit oscillating? The common way to tell that the set is oscillating is to watch the plate meter. When the circuit goes into oscillation, the meter will show that less plate current is flowing than when the circuit is out of oscillation. The 6C5 will draw about 10 milliamperes when in oscillation. The plate current will rise when the set goes out of oscillation.

You may find that this circuit will oscillate over the whole condenser range but will show the lowest dip at one setting.

A neon tube is a good oscillation indicator. The size and wattage of the neon tube are of little importance. The neon tube will glow when you touch its base to the ends of the plate coil when the circuit is in oscillation. The tube will also glow if you touch any part of the tank circuit except the part connected to B minus. It may glow when you hold it near other parts of the circuit carrying radio-frequency currents.

How much power is the oscillator generating? You often find it useful to know how much power is being generated in the oscillator tank circuit. You may wish to use this power to drive an

amplifier, or you may wish to couple the oscillator to an antenna and use it as a low-powered transmitter. The amplifier or the antenna is then the load on the oscillator. (You may connect your oscillator to an antenna only if you hold an amateur operator's license and a station license.)

A simple way to observe the power the oscillator generates is to couple an ordinary incandescent lamp to the oscillator. This is done by means of the dummy antenna, which consists of a tuning coil and condenser and a lamp load. The dummy antenna is the load into which the oscillator is operating. Current induced in the pickup coil by the tank coil is used to light the lamp. The lamp is the actual load on the oscillator. Here the current is changed to heat. (The construction of the dummy antenna is described in Part 2 of this chapter.) The intensity of the light shows the results of adjustments you make and is an indication of the power developed by the oscillator. The dummy antenna is also excellent to use when you study the operation of the oscillator under load.

How to Measure Power Developed by the Oscillator

Step 1. Turn on the power to the oscillator.

Step 2. Tune the oscillator until the plate meter shows the lowest reading.

Step 3. Screw a lamp into the dummy antenna socket. The size of the lamp you select will depend on the tube you use in your oscillator. The 6V6 will develop the least power, the 6F6 more, and the 6L6 the most.

Couple the dummy antenna to the oscillator by placing its coupling coil near the plate end of the oscillator tank coil.

Step 4. Tune the dummy antenna to resonance with the oscillator. At resonance the lamp's glow is brightest. Move the coupling coil toward and away from the oscillator tank coil, and note the effect of coupling on the glow of the lamp.

As you draw power from the oscillator by closer coupling or by tuning the dummy antenna to resonance, the reading of the plate meter will increase. Power drawn from the oscillator by the dummy antenna load is supplied by the plate current, which increases as power is absorbed by the dummy antenna.

Bell Laboratories Record

MICROMANIPULATOR FOR HANDLING SEMICONDUCTOR DEVICES

The tiny pieces of silicon and germanium are so small and require such careful and precise handling that this special machine called a micromanipulator must be used.

Step 5. Retune the oscillator until you again have the lowest reading. At this point your oscillator is generating the greatest amount of power possible at the voltage at which it is operating.

How to Change the Power Output of the Oscillator

You may wish to increase the output of the oscillator when you use it for a transmitter. The signal you put on the air will then have the greatest possible strength. Also, when you use this oscillator to drive an amplifier like the one described later in this chapter, you must be able to adjust the amount of power the oscillator delivers to the amplifier.

The power developed by this self-excited triode oscillator is controlled by the grid excitation. The grid excitation is the amount of energy supplied to the grid coil by the plate part of the tank coil.

How to Adjust Grid Excitation

Step 1. Place the dummy antenna near the oscillator tank coil.

Step 2. Set the clip at the center of the tank coil. You can handle this clip safely with the B power turned on.

Step 3. Read the plate milliammeter. Tune the oscillator for the lowest reading of the plate meter. Watch the glow of the lamp in the dummy antenna to see the effect that changes in the grid excitation have on the power developed by the oscillator.

Step 4. Move the position of the clip, and retune for the lowest plate current. Continue until you find the position of the tap at which the glow of the lamp is brightest.

The position of the clip controls grid excitation by changing the feedback from the plate part of the coil. Move the clip toward the plate end of the coil to increase the grid excitation and toward the grid end to reduce the excitation. This setting is different for each tube.

When the clip is too near the grid end of the coil, the set will stop oscillating, since there is too little grid excitation. The plate current will increase. The size of the grid leak also affects the excitation. Try different sizes of grid leak to get the proper grid excitation.

Questions

1. When the clip is moved toward the plate end of the coil, is the grid excitation increased or decreased?

2. What happens to the plate current when the set stops oscillating?
3. Describe several methods for testing to see whether the set is in oscillation.
4. State where strong direct-current shocks may be encountered on this set.

Measuring the Input Power of a Hartley Oscillator

Power input is important to radio amateurs because the Federal Communications Commission regulates the size of amateur transmitters by this means. Amateurs describe their transmitters by the power *input* to the circuit connected to the antenna.

Step 1. Couple the dummy-antenna load to the tank coil.

Step 2. Measure the plate voltage with a high-resistance voltmeter (see Fig. 411 for its connection in the circuit).

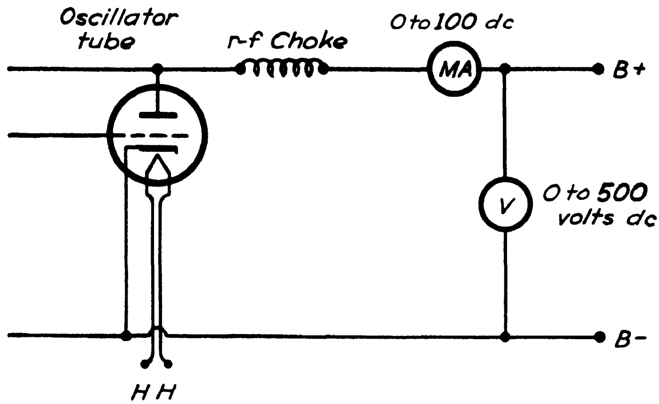


FIG. 411. Connect a voltmeter and a milliammeter as shown here to measure the power input to the oscillator.

Step 3. Measure the current in the plate circuit with a 0 to 100 direct-current milliammeter.

Step 4. Compute the power input by using this formula

Voltage × current (in milliamperes) = milliwatts input
250 volts × 20 milliamperes = 5000 milliwatts

Divide the product (in milliwatts) by 1000 to get the watts input:

$$5000 \div 1000 = 5 \text{ watts}$$

Questions

1. What is the power input in a Hartley circuit operated on 300 volts and a plate current of 20 milliamperes?
2. When connected as shown in Fig. 411, does the milliammeter measure the current taken by the voltmeter?

How the Hartley Oscillator Works

Electrons surge through the tube. When the filament heater in the tube is heated, a space charge immediately builds up around the cathode (see Fig. 412). Now when you turn on the B supply, electrons are pulled to the plate out of the space charge, and a current flows through the tube. The electrons flow through the tube and the plate circuit on their way back to the B supply.

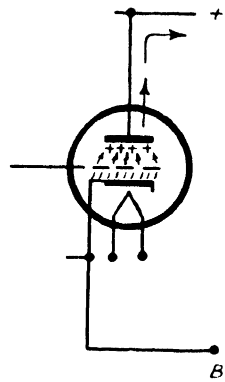


FIG. 412. Electrons from the space charge around the cathode are drawn to the positive plate.

The Radio-frequency choke coil stops the surge. The electron surge through the tube is opposed by the choke coil (see Fig. 413). The back voltage of the choke coil against the sudden increase of current drives the electrons onto side *A* of the blocking condenser. The surplus electrons forced on side *A* drive electrons off side *B*.

The stator plates fill. The electrons driven from side *B* of the blocking condenser rush to the tank coil, but the back voltage set up by the sudden surge of electrons forces them onto the stator plates *S* of the tank tuning condenser (see Fig. 414). As side *S*

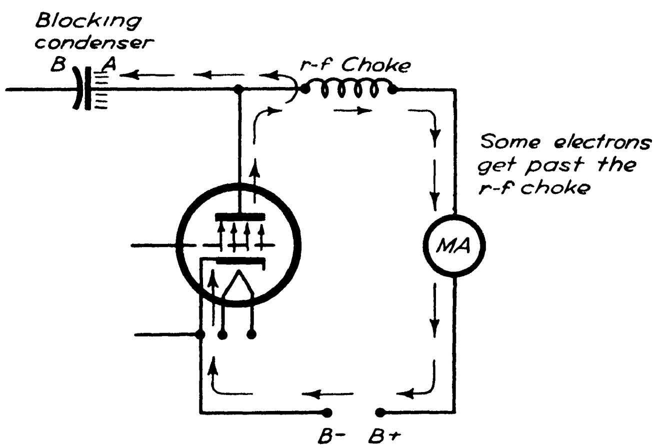


FIG. 413. The radio-frequency (r-f) choke stops the sudden rush of electrons. A few electrons get through but most of the electrons in the sudden surge cannot get through the choke. They are, instead, driven to the blocking condenser.

of the tank condenser fills, the electrons already on these plates build up a back voltage.

The first surge starts through the tank coil. The back voltage on side *S* of the tank condenser drives electrons to the tank coil

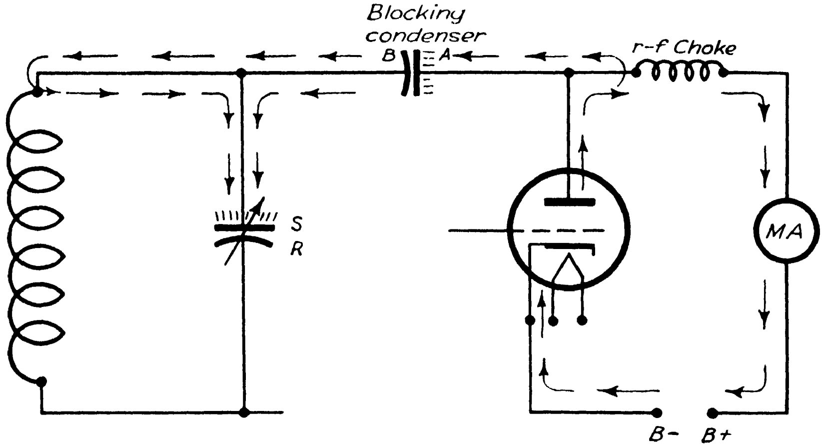


FIG. 414. The electrons are driven from the blocking condenser to the tank coil and condenser. The back voltage set up in the coil by the surge drives electrons onto side *S* of the tank tuning condenser.

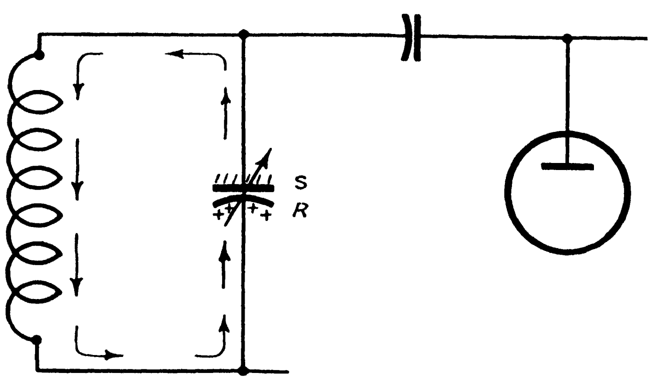


FIG. 415. As the electron surge rushes from side *S* of the condenser through the tank coil, it builds up a magnetic field around the coil.

(see Fig. 415). As the electrons rush from the stator plates, through the tank coil, and into the rotor plates of the tank condenser, the electron current builds up a magnetic field around the coil.

As the current flow decreases, the collapsing field around the

coil sets up a voltage which tries to pull more electrons from the stator plate to keep the surge going. This completes the first part, or alternation, of one cycle. This is the first half of one radio-frequency oscillation.

The grid becomes negative. The electrons surge from the tank coil into the rotor plates of the tank condenser and drive electrons onto the grid condenser, which in turn drives electrons to the grid of the tube and makes it more negative (see Fig. 416). The grid finally becomes negative enough to cut off the flow of electrons

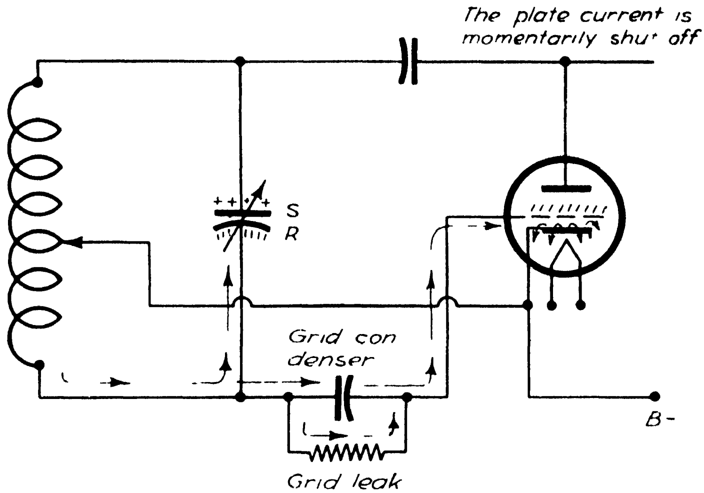


Fig. 416. At this instant the electrons driven onto the grid of the tube shut off the flow of electrons through the tube.

through the tube. This completes half of the surge, or radio-frequency oscillation.

The reverse surge starts. As the current flow through the tube stops, the electrons forced on the rotor plates of the tank condenser drive a surge back through the tank coil to the stator plates of the tank condenser (see Fig. 417). No current is flowing from the plate of the tube to oppose the return of the electrons through the coil, because the grid is at cutoff. The grid is kept negative by the grid condenser and the grid leak long enough for this surge to be completed. The sizes of the condenser and the grid leak are selected to fit the frequency at which the oscillator will work.

The grid again becomes less negative. As the current surge through the tank coil from the rotor to the stator begins to die out,

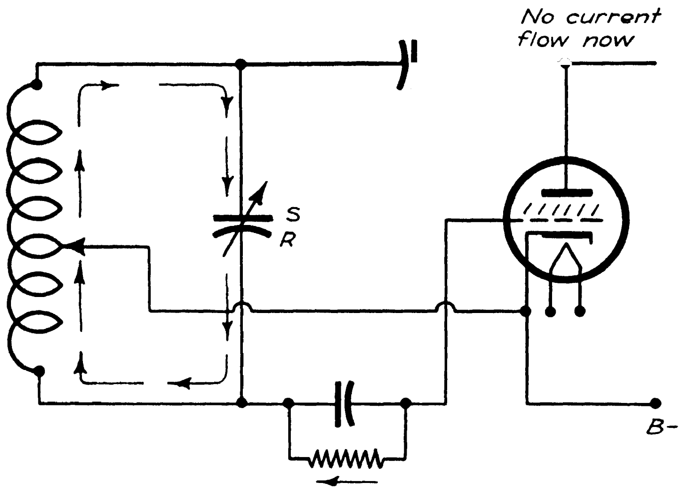


FIG. 417. The electron surge returns from the rotor plates back through the coil to the stator plates. The grid is kept negative by the action of the grid leak.

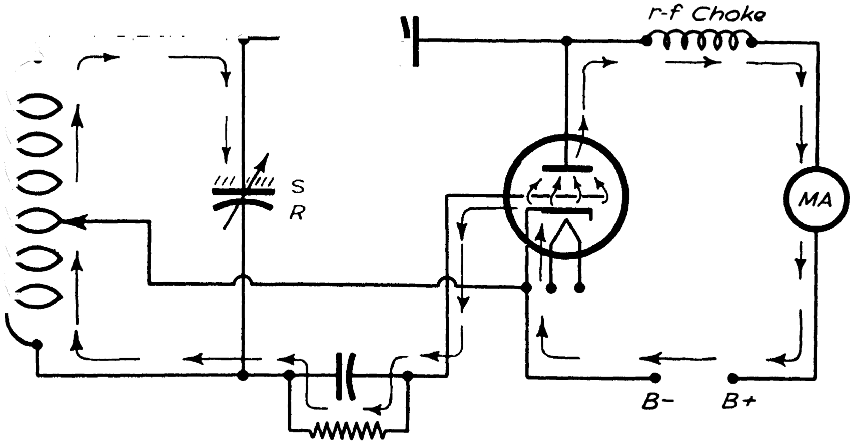


FIG. 418. The collapsing field around the tank coil pulls electrons off the grid and another surge starts.

the collapsing magnetic field built up around the tank coil by the first surge tries to keep the current flowing (see Fig. 418). This pull draws electrons from the grid, making it less negative, and electrons again rush through the tube. The pull of the less negative grid helps the pull of the plate, and another surge begins.

Grid excitation. The grid-return wire is connected near the center of the tank coil. When the tap is moved toward the grid

end of the coil, more voltage is induced in the grid part of the coil, and the set oscillates with more power. The position of the grid-return clip controls the grid excitation.

This whole process occurs in the circuit at over 3,000,000 cycles per second. The Hartley-oscillator circuit is capable of oscillating both at the comparatively low frequencies used on broadcasts of millions of cycles per second and at the ultrahigh frequencies used in the 10-, 5-, and $2\frac{1}{2}$-meter sets.

Questions

1. Explain why side A of the by-pass condenser is filled with electrons when a surge flows onto the plate of the tube.
2. When a surge starts down through the plate part of the tank coil, will the grid end of the grid coil force electrons onto the grid or draw electrons away from it?
3. Will this increase or decrease the flow of the plate current?
4. When the impedance, or back pressure, of the tank coil is overcome, where do the electrons which were on the stator plate of the tuning condenser go?
5. What effect will this flow have upon the grid?
6. What holds the grid negative long enough to keep the plate current shut off while the condenser rotor plates unload back through the tank coil?
7. What effect will the tank coil have upon the grid when the current upward through the tank coil suddenly decreases?

PART 2: CONSTRUCTION OF A DUMMY ANTENNA

Use the dummy antenna in place of the regular antenna when you are experimenting with oscillators or transmitters and do not

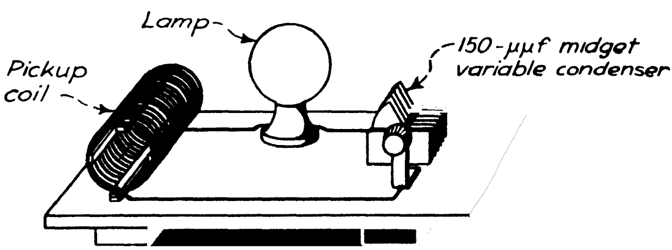


FIG. 419. The dummy antenna. The lamp size depends on the tube you are using in the oscillator circuit.

wish to send out radio waves. The dummy antenna is a coil-and-condenser tuning circuit with a lamp connected in series. The lamp is used as a resistance to absorb the electrical energy picked up by the coil from the oscillator tank circuit (see Fig. 419).

How to Build and Wire It

The Coil. Wind a coil the same way the tank coil was wound, as explained in Part 1 of this chapter.

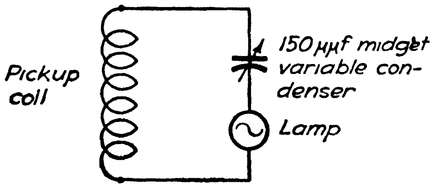


FIG. 420. The circuit for the dummy antenna.

The Condenser. Use a 150-micromicrofarad midget variable condenser similar to the tank-circuit condenser.

The Lamp Indicator. Wire a lamp socket in series with the coil and condenser (see Fig. 420).

How to Operate It

Screw a lamp in the socket large enough to absorb the energy delivered by the oscillator.

Place the dummy antenna so that the pickup coil is near the oscillator tank coil. Tune the dummy antenna condenser to the point at which the lamp glows most brightly. At this point the plate milliammeter should show an increase in the plate current.

Connect the 10-watt lamp to the 110-volt circuit to see the full brilliance of the lamp before using it in the dummy-antenna circuit. The glow of the lamp shows the amount of current the dummy antenna draws from the oscillator.

Power Input. The power input is found by multiplying the oscillator plate voltage by the plate current.

Problem. When 250 volts is used on the oscillator plate and the plate current is 40 milliamperes, find the power input to the oscillator.

$$\begin{aligned} 250 \text{ volts} \times 40 \text{ milliamperes} &= 10{,}000 \text{ milliwatts} \\ 10{,}000 \text{ milliwatts} \div 1000 &= 10 \text{ watts input to the oscillator} \end{aligned}$$

Screw a 10-watt lamp in the socket. Tune the set, and compare the glow of the lamp in the dummy antenna to the glow of another 10-watt lamp connected to the lighting circuit. The output of the oscillator can be judged by the glow of the lamp in the dummy antenna.

An oscillator with 10 watts input will not light a 10-watt lamp to full brilliance because the oscillator efficiency is less than 100 per cent.

PART 3: THE ABSORPTION TYPE OF FREQUENCY METER

The absorption type of frequency meter is valuable to you because you can use it to find the fundamental frequency at which your oscillator is operating.

If your oscillator was tuned to a frequency of 3600 kilocycles, this is its fundamental frequency. It may have a second harmonic at 7200 kilocycles, a third harmonic at 10,800 kilocycles, and so on, each higher harmonic being progressively weaker.

The fundamental-frequency setting gives the strongest signal. A harmonic signal, which is twice the fundamental, is much weaker. A higher harmonic, three times the fundamental, is still weaker.

How to Build the Meter

Make a base of wood 4 inches wide and 6 inches long (see Fig. 421).

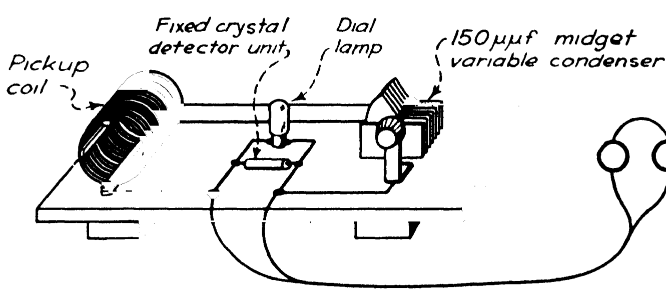


FIG. 421. The absorption-type frequency meter. You may use the crystal detector and earphones by unscrewing the dial lamp. Or you may use the dial lamp indicator by raising the cat whisker and removing the earphones.

The Condenser. Mount a 150-micromicrofarad midget variable condenser on the baseboard. Mount a socket for a flashlight lamp near the binding post, so that the wiring can be short and direct.

The Coil. Make a coil for each band on which you expect to test frequencies. These coils must be of the same size as the oscillator coil.

How to Operate the Meter

The absorption type of frequency meter is a tank tuning circuit to which is attached a light, or detector, and phones, to show when the circuit is in resonance with the frequency you are trying to

measure (see Fig. 422). The flashlight lamp is used to indicate resonance by the strength of the glow. Sometimes a crystal detector and a pair of phones are used in place of the flashlight globe. The loudest sound will be heard in the earphones at resonance.

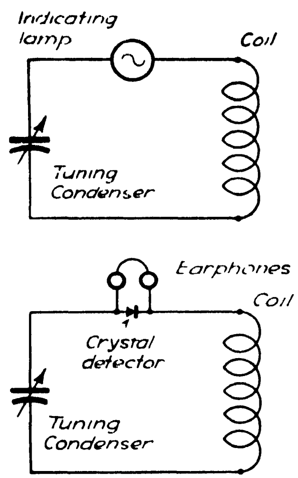


FIG. 422. The absorption type frequency-meter circuits.

The absorption type of meter is not highly accurate. It will be accurate to within 20 to 30 kilocycles. Use a monitor and a receiver for more accurate measurements. Since it responds only to the fundamental frequency, the absorption type of meter is valuable for setting the transmitter to a definite frequency band. A monitor will respond to harmonics.

How to Calibrate the Meter

A good way to calibrate the frequency meter is to use a signal generator of the type used by radio servicemen. Use an instrument of good quality if you want accurate results.

Attach to the signal generator a temporary coupling coil of five turns of flexible wire about 2 inches in diameter.

Set the pickup coil of the frequency meter near the coupling coil.

Set the signal generator to deliver a modulated signal. Use the crystal detector and the earphones to pick up the signal on the frequency meter.

Set the signal generator to 3000 kilocycles (3 megacycles). Turn the condenser of the frequency meter until you hear the loudest signal.

How to Locate Points on the Calibration Curve

You can draw the calibration curve on squared cross-section paper. Draw two heavy lines on the paper, as shown in Fig. 423. Label one line "Condenser Setting" and the other "Frequency." Make a dot on the squared paper above the condenser setting and opposite the frequency to which the generator is set (see Fig. 423).

You will need several points on your cross-section paper to draw the calibration curve. Then points represent the condenser setting

for the different frequency settings of the signal generator. Get a number of points on the paper by taking readings every 500 kilocycles between 3000 kilocycles and 4000 kilocycles.

Sketch a light line through the points. This line may not hit each point exactly. But make the line a smooth curve with no sudden jogs or bends. After you have checked the points, draw in

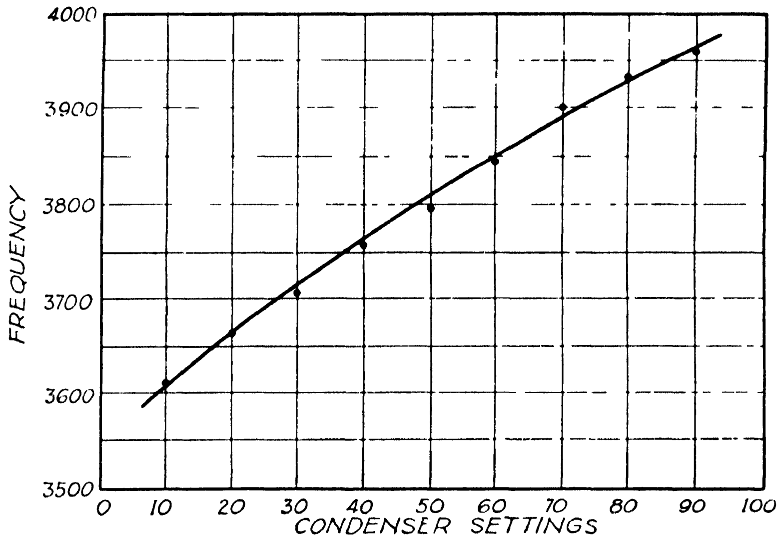


FIG. 423. The calibration curve for the frequency meter. The shape of this curve will depend on the shape of the plates of the variable condenser you use in the absorption frequency meter.

the curve as a heavy line. A draftsman's French curve is often used to draw the curve.

How to Use the Curve

You can easily tell the frequency at which your oscillator is operating by a glance at the curve. Read the setting of your tuning condenser. Then run up to the curve above this setting and across to the frequency.

You can also set your oscillator to a definite frequency by reversing the process. Note the frequency you want. Run across the chart to the curve, and look below to find the setting of the condenser for this frequency.

Questions

1. Will an absorption type of meter respond to the harmonics produced by an oscillator?

2. How can you tell when the meter is set at the same frequency as the receiving set?

PART 4: THE TUNED-PLATE TUNED-GRID OSCILLATOR

This oscillator circuit is fundamentally different from the Hartley oscillator. In the tuned-plate tuned-grid circuit, energy is fed back between the plate and the grid of the tube instead of through the

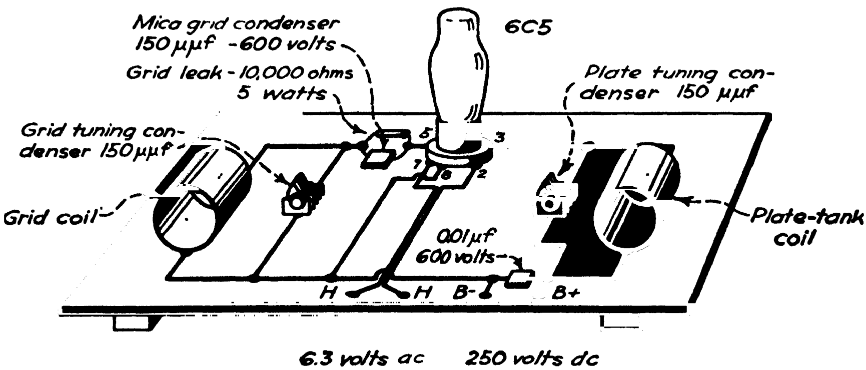


FIG. 424. The layout of parts for the tuned-plate tuned-grid oscillator.

coil. A tank circuit is built into both the grid circuit and the plate circuit.

The tuned-plate tuned-grid circuit will tune over a wide range of frequencies.

How to Build the Set

The Baseboard. Mount this oscillator on a larger board. A convenient size is 9½ inches by 20 inches. This allows sufficient space so that the wiring will not be crowded. Mount the parts as shown in Fig. 424.

Coils. Both the grid and plate tank coils must be the same size, and both must be wound with the same size and number of turns of wire. See "How to Wind the Oscillator Tank-circuit Coil" in Part 1 of this chapter.

Condensers. Use two 150-micromicrofarad midget variable tuning condensers in the tank circuit. Use a molded mica condenser of 600-volt rating for the grid condenser and the blocking condenser.

How to Wire the Set

Wire the tank circuit, shown in heavy lines in Fig. 425, with No. 14 enameled wire. The other wiring of the set may be with push-back or other convenient wire, about No. 18.

Any of the tubes suitable for the Hartley oscillator can be used with this oscillator. The 6V6 or the 6F6 are good oscillator tubes.

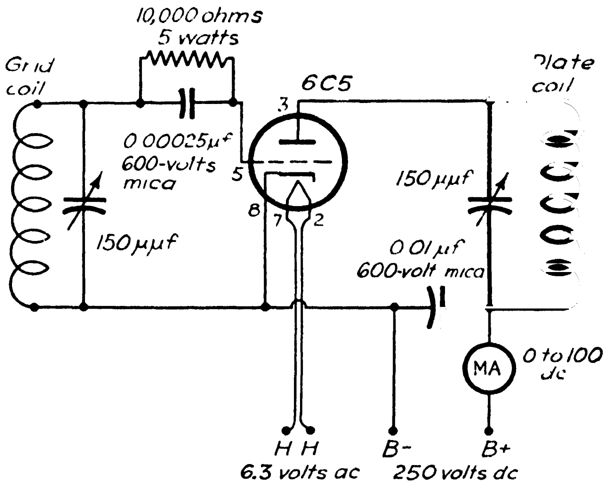


FIG. 425. The schematic circuit of the tuned-plate tuned-grid oscillator.

How to Operate the Set

Connect a 0 to 100 direct-current milliammeter between the power supply and the B-plus connections on the oscillator. Use this as an oscillation indicator and for tuning during your experiments.

Check the tuning of both the plate and grid circuits with an absorption type of frequency meter. If one circuit is tuned to 40 meters and the other to 80 meters, the set will not oscillate.

Step 1. Turn on the heater current. Turn on the B voltage after the cathode is hot. When the plate voltage is less than 400 volts, both heater and plate power may be turned on together.

Step 2. Turn the plate tank tuning condenser to the desired frequency setting. If the plate current is high, the circuit is not in oscillation. Swing the grid condenser until the meter dips. This indicates that the circuit is oscillating.

Step 3. Adjust the grid tank condenser until the lowest plate current is shown by the plate milliammeter.

Step 4. Tune the plate tank condenser. Tune for the lowest plate current. If the set stops oscillating, the plate current will rise. Now give the grid tuning condenser a final readjustment to provide enough excitation.

In Part 1 of this chapter, you learned how to check for oscillation.

How to Couple a Load to the Oscillator

Step 1. The load may be either a dummy antenna or an amplifier circuit. Bring the coupling coil of the load near the plate-tank coil. The plate milliammeter will show a rise in current as the load draws power from the oscillator.

Step 2. Adjust the grid tuning condenser for the highest current reading.

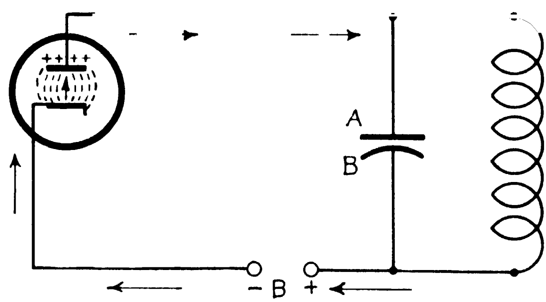


Fig. 426. The first surge starts through the plate circuit.

Step 3. Readjust the tank condenser for the desired frequency.

How It Works

Turn on the set. When the cathode is heated, it throws off electrons which form a space charge around it. When the B supply is turned on, it drains electrons off the plate, making the plate highly positive. Electrons surge from the space charge to the positive plate (see Fig. 426). This causes a current of electrons from the plates to surge through the tank coil to return to the B supply.

The tank coil opposes the surge. When the surge of electrons reaches the plate-tank coil, the sudden rush of current causes a *back voltage* to develop in the coil which retards the free flow of electrons to the B supply. The electrons which cannot flow through the coil easily flow instead into side *A* of the tank tuning condenser

(see Fig. 427). This makes side *A* negative and drives electrons off side *B* to the B supply.

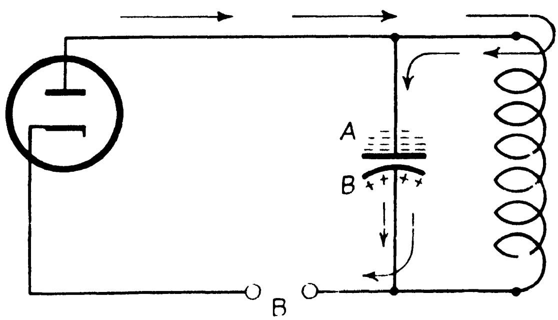


FIG. 427. The tank coil opposes the surge and charges the tuning condenser. Electrons are forced on side *A* and are drawn off side *B*.

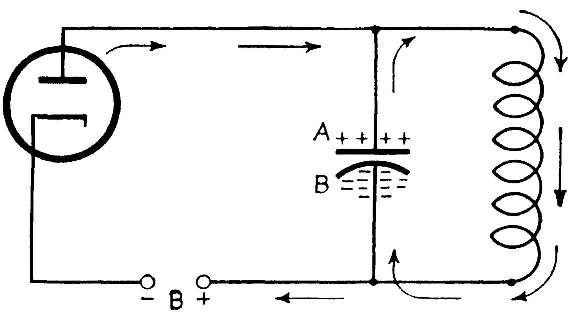


FIG. 428. The surge "breaks" through the tank coil. Electrons now rush through the coil and begin to fill side *B* of the tuning condenser.

The surge breaks through the tank coil. When the pull of the B supply overcomes the back pressure of the tank coil, the first electron surge flows through the tank coil. The tank-coil pull empties side *A* of electrons and loads them on side *B* (see Fig. 428). Side *A* is now positive and side *B* negative.

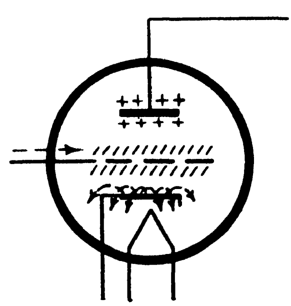


FIG. 429. The grid now becomes negative.

The grid shuts off the plate current. When the electron surge has reached side *B*, side *A* and the tube plate are very positive. The plate and the grid of a three-element tube have enough surface to act as a small condenser. The positive plate of the tube

attracts electrons to the grid from the grid circuit (see Fig. 429). The grid now becomes negative.

During the second surge through the plate circuit, some electrons flow through the grid circuit and reach the grid condenser. This drives more electrons to the grid (see Fig. 430). The grid becomes negative enough to shut off the flow of electrons to the plate.

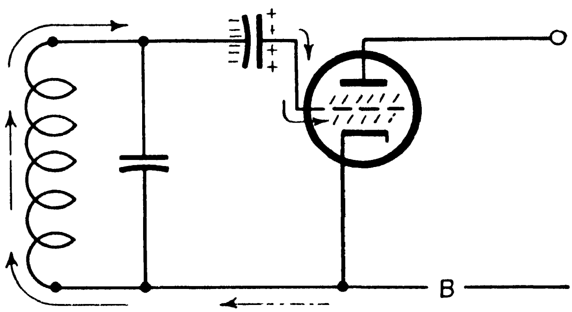


FIG. 430. When the grid is negative, no electrons flow to the plate.

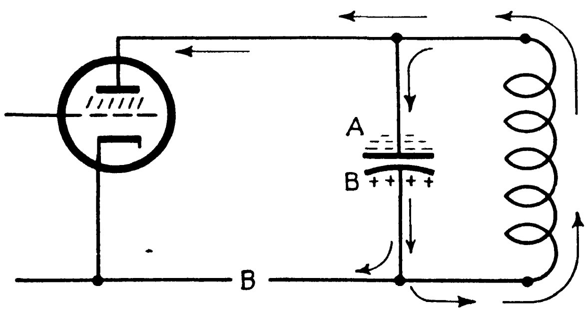


FIG. 431. The second surge now starts through the tank coil.

The surge returns to side *A*. The grid is so negative that no current can flow through the tube. The grid leak holds the electrons trapped on the grid until the heavy load of electrons on side *B* can surge back to side *A*. This makes *A* negative. Some electrons surge to the tube plate and make it very negative. This is the beginning of the second surge (see Fig. 431). The first and second surges are one cycle, or oscillation.

The grid again swings toward positive. By the time the surge has reached side *A*, the electrons on the grid have leaked off through the grid leak and the grid has become less negative (see Fig. 432).

The grid is made more positive by the negative plate helping to push the electrons off the grid.

The grid tank circuit oscillates. When the negative plate drives electrons off the grid, electrons are driven to the grid-tank condenser, side *C*, and surges start through the grid tank coil as in the plate tank coil (see Fig. 433).

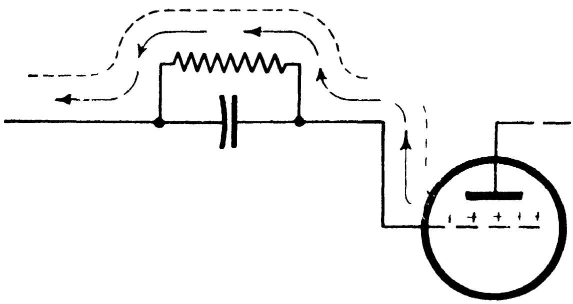


FIG. 432. Electrons leak off the grid through the grid leak and make the grid less negative.

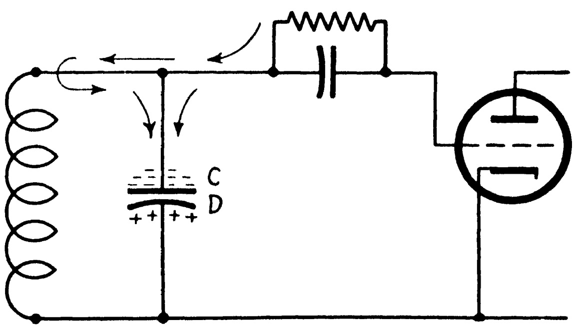


FIG. 433. The grid tank circuit oscillates.

The grid tank coil must be tuned to the same frequency as the plate tank coil so that the surges in the grid coil will occur in step with the kicks from the grid.

The grid tank circuit acts as a timing circuit. Electron surges from the grid-tank coil make the grid more positive when the negative plate draws electrons from the grid. It also helps make the grid more negative when the plate is positive. Electron surges from the grid-tank coil make the grid more positive when the negative plate draws electrons from the grid. It also helps to make the grid more negative when the plate is positive.

The third surge starts. The grid, now less negative, lets electrons surge to the plate again. This third surge fills plate *A* and rushes through the tank coil. This surging continues oscillating back and forth through the tank coil as a powerful radio-frequency oscillating current.

This surging is kept going by the pushes from the plate of the tube.

What is the purpose of the grid condenser and leak? The grid leak has enough resistance to hold a considerable quantity of electrons on the grid and on side *C* of the grid tank condenser. This keeps the grid negative enough so that during most of the cycle of the grid tank oscillation, no current flows in the plate circuit. This gives the surge time to return from side *B* through the plate tank coil to side *A*. This surge is ready to start back through the tank coil just as the grid triggers the plate current and shoots another surge to the plate circuit. The grid then acts like an automatic on-and-off switch.

The plate current flows in jerks or spaced surges timed by the grid, giving the electron surges oscillating between side *A* and side *B* through the tank coil a boost, or kick, at just the proper instant to build up continuous oscillations in the plate tank circuit.

How is the plate-current meter read? When the plate tank circuit is properly tuned, very little current flows through the tube, because during part of each cycle this current is shut off by the negative grid. These timed plate-current surges build up a powerful tank-circuit oscillation.

But if the tank circuit is not properly tuned, the surges in the plate circuit and in the grid circuit will be out of step. The grid now does not become negative enough to shut off the plate current during part of each cycle, and so much more plate current flows. The plate milliammeter reading goes up.

Questions

1. When side *B* of the tuning condenser in Fig. 428 is negative, what is the charge on the plate? What charge does the plate produce on the grid?

2. Is the grid positive or negative when the electrons flow from plate *B* back to plate *A*, as in Fig. 431?

3. When plate *A* has a heavy negative charge, as in Fig. 427, what will be the charge on the plate? What charge does the plate produce on the grid? What effect will the grid now have upon the plate current?

4. Show the current flow in the grid circuit when side *B* of the condenser in the plate circuit is negative, as in Fig. 428.

5. Trace the current flow in the grid circuit when side *A* of the condenser in the plate circuit is negative.

6. What would be the effect on the operation of this set if the grid leak did not have enough resistance?

PART 5: THE OSCILLATING QUARTZ CRYSTAL

The self-excited oscillators you have just been studying have one serious defect when they are used in a transmitting set. Their frequency is seldom steady. Their frequency will change when the plate voltage changes and as the tube and circuit become warmer. Self-excited oscillators must be carefully designed to keep the frequency reasonably steady. Federal laws require that a transmitting set be built and operated so that it will operate within a narrow band of frequencies. This is done to prevent interference with sets operating on nearby frequencies. When the frequency of a transmitting station shifts, it interferes with other stations and is hard to keep tuned in at a receiver.

There is a type of oscillator that will operate constantly on only one frequency. It employs a method of frequency control using the properties of crystals of pure quartz.

Question

Make a list of things which will cause the frequency of a transmitter to vary.

Characteristics of quartz crystals. Quartz occurs in nature in the form of six-sided crystals of different sizes that terminate in a pointed end (see Fig. 434). The faces of the crystal are flat and smooth, and the crystals are often transparent.

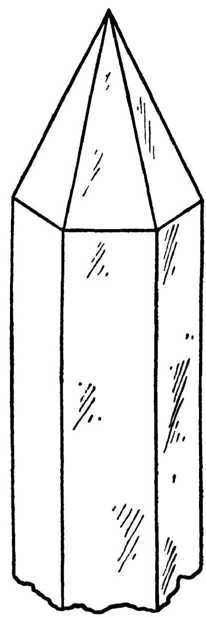


FIG. 434. This shows the shape of one end of a quartz crystal.

Quartz is a highly elastic solid material. If put under pressure, the molecules of the quartz will be compressed very slightly and the crystal will tend to squeeze and flatten as would a rectangular piece of rubber if put under pressure. The thickness of the quartz may not change more than

a fraction of a thousandth of an inch. When the pressure is removed, the quartz will spring back into shape and then expand slightly just as a steel spring will whip back and forth (oscillate) when it is compressed and then released. The molecules of the quartz crystal will similarly continue to vibrate for a short time.

Now, when the quartz is compressed, it develops a charge, and a small voltage appears between the two surfaces of the quartz. The harder the quartz is squeezed, the greater the voltage between the two surfaces. Charges of opposite polarity appear when the quartz expands and the voltage between the two surfaces is in the opposite direction.

If two metal plates are placed against the two surfaces of the quartz and then connected to a battery, the difference in voltage between the two plates will cause the quartz to flatten slightly as if it were squeezed. When the voltage is shut off, the molecules of the crystal will spring back into shape and will continue to oscillate, just as the released spring oscillates, at a frequency that depends on the thickness of the quartz. The oscillating crystal generates voltage surges which you can use to control the frequency of an oscillator. You will see how this is done later in this chapter.

This peculiar property of a quartz crystal is called the *piezoelectric effect.* Tourmaline crystals also are piezoelectric, but they are quite expensive. The tourmaline crystal is used in very high frequency circuits which require quite thin crystals.

Rochelle-salt crystals, which are also piezoelectric, are used in crystal microphones and in phono pickups. The rugged quartz crystal is better fitted for use in oscillators.

Note. The quartz crystal is entirely different from the silicon or galena crystals used for a detector in the receiving sets described in Chapter 9.

How the quartz crystals are prepared for use in radio circuits. Flat, thin slabs are cut out of large quartz crystals with rotary diamond saws. Blanks for use in radio circuits are cut in several different ways. The blanks from which the finished radio crystals that you will study are made are cut with edges parallel to the long edges of the original quartz crystal. In Fig. 435 you can see the position of the X cut and the Y cut in the original crystal. The X cut is taken at right angles to two flat surfaces, or sides, of the

crystal. The Y cut is taken between the two corners of the crystal. There are also a number of other cuts made at different angles for special purposes.

The frequency of vibration. Each crystal, when properly cut and finished, will vibrate at one fixed frequency. This ability of a crystal to vibrate at only one frequency is the characteristic that makes it valuable for radio use. The thickness of the slab determines the frequency at which the crystal will oscillate. Thick

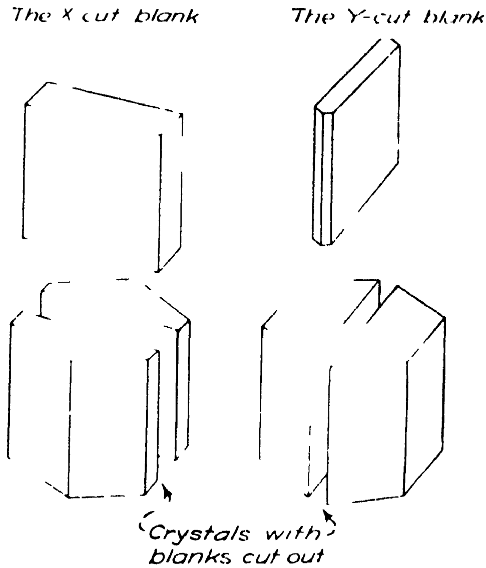


FIG. 435. Here are two crystals with blanks cut out. Note the different direction of the cut for the X-cut crystal and for the Y-cut crystal.

crystals of a given type of cut vibrate more slowly (at a lower frequency) than do thin crystals. An X-cut crystal which will oscillate at the rate of 1800 kilocycles (1,800,000 cycles) per second is about the size and thickness of a dime. Y-cut crystals are a little more than half as thick for the same frequency.

How finished crystals are prepared. After the rough blank has been sawed out of the rock crystal, it must be ground until it is perfectly flat and the same thickness throughout.

How the crystal is connected in the circuit. A finished crystal blank is placed in a special holder. There are many types of holders on the market. Fundamentally, a holder consists of two metal plates placed on each side of the crystal. The plates are

ground perfectly flat and smooth. They are nickel-plated to prevent corrosion.

A commonly used crystal holder is one in which the crystal rests between two metal plates in an enclosed holder (see Fig. 436). The upper plate is laid loosely on the crystal. Connection to the two metal plates is made by wires from each plate to a terminal pin on the crystal holder. A cover keeps out dust and dirt particles (see Fig. 436). In some crystal holders the upper plate is spaced away from the crystal. Still other crystal holders are arranged so that this spacing may be adjusted to make small changes in frequency at which the crystal will operate.

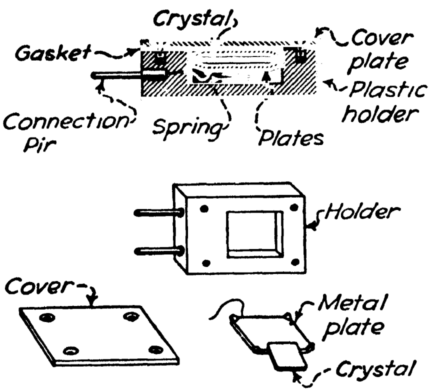


FIG. 436. This shows the construction of one type of crystal holder.

How the crystal operates. The two plates between which the crystal rests form a condenser with the crystal as a dielectric. When there is no voltage between the two plates, there is no strain on the crystal. But when one plate is made positive and the other is made negative by voltage, the two plates are of opposite polarity. This places the crystal under an electrical strain, or pressure, and causes it to flatten out slightly. When the voltage is removed the crystal springs back to its original shape and beyond it, oscillating after the voltage is removed. The speed at which it vibrates depends both on its thickness and the way it was cut from the raw crystal.

Now, if we connect an alternating voltage across the metal plates that has the same frequency as the frequency at which the crystal naturally vibrates, the crystal will oscillate as long as this alternating voltage is applied. If the voltage alternates at any other frequency, the crystal will not oscillate. The rock crystal vibrates freely at one frequency, but at any other frequency it remains motionless.

The crystal will produce an alternating voltage. If you apply a pressure to the crystal at regular intervals by means of an alter-

nating voltage, it will produce an alternating voltage of the same frequency as that at which the pressure is applied. But the applied voltage must be at the frequency for which the crystal is ground; otherwise, the voltages generated by the crystal will oppose the applied voltages. When the applied voltage and the generated voltage have the same frequency, the natural tendency of the crystal to oscillate causes the applied voltage and the generated voltage to aid each other.

Temperature affects frequency. An X- or a Y-cut crystal will oscillate at a slightly different frequency when the temperature changes. When such crystals are used in broadcast sets, they are placed in ovens in which the temperature is kept uniform by a thermostatically controlled electric heater. This prevents frequency changes because of changes in operating-room temperature. (There are cuts other than the X and Y which have less frequency change per degree of temperature and are used where greater accuracy is demanded.)

These frequency changes are relatively small as compared with the changes that the same temperature variation would cause in a self-excited oscillator, and they would not be important if broadcasting stations were not compelled by law to hold their frequencies so nearly constant. A broadcasting station on 1500 kilocycles, for example, must keep its carrier frequency constant to within 60 cycles (50 cycles in 1,500,000, or 50/1,500,000 = 0.003 per cent).

Questions

1. Will a crystal oscillate if its sides are not parallel?
2. What effect does thickness have upon the rate of vibration of a crystal?
3. Will the crystal oscillate if the impressed alternating current has a frequency different from the rate of vibration of the crystal?

PART 6: THE CRYSTAL-OSCILLATOR CIRCUIT

How to Build and Wire the Set

Parts for the set. Screw two octal sockets to the baseboard, one for the crystal holder and one for the tube. Also mount a four-prong wafer socket on metal standoff tubes for the plug-in coil (see Figs. 437 and 438). The tank condenser in the plate circuit is the same as the one used in the Hartley circuit. The tank coil is wound on a standard 1½-inch diameter, four-prong, plug-in coil form. Wind on closely 25 turns of No. 18 enameled wire. Start

the winding near the top of the coil form. Use a 50,000-ohm 1-watt grid-leak resistor.

Use a 1-watt bias resistor of 200 ohms to 400 ohms. Try different values to find the size at which you get the greatest output

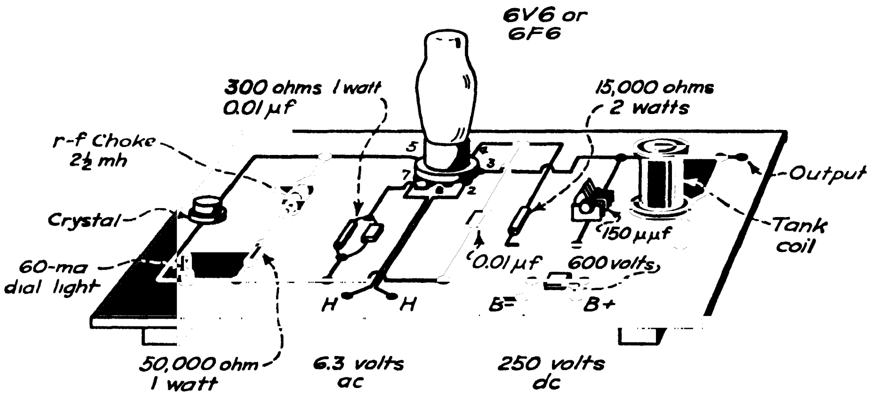


FIG. 437. The layout of parts for the crystal oscillator.

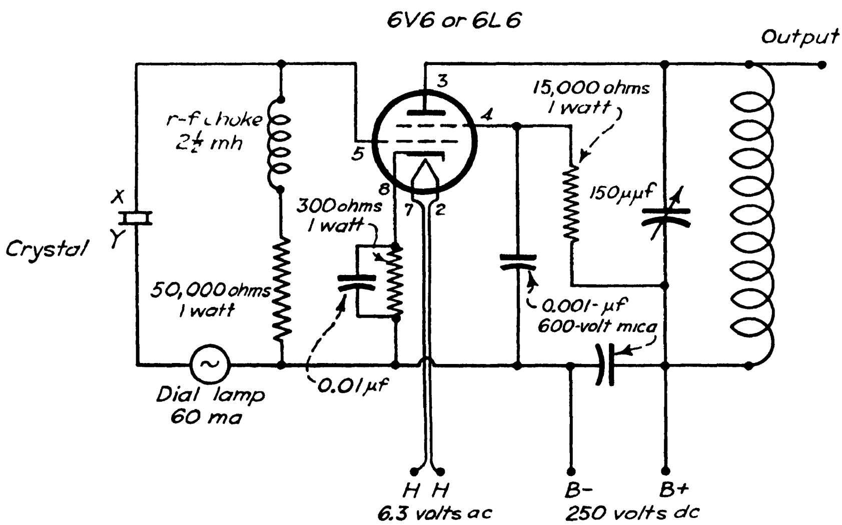


FIG. 438. The schematic wiring diagram for the crystal oscillator.

from the oscillator. The by-pass condenser is a 0.01-microfarad paper condenser with a 600-volt rating.

Note the screen by-pass condenser, with a 0.01-microfarad 600-volt capacity. The screen resistor is 15,000 ohms with a 1-watt rating. You may also try other resistor values to find the effect

that the changes in screen voltage have on the output of the oscillator. Connect a 60-milliampere dial lamp in the grid circuit as shown in the diagram. If too much grid current flows, the crystal will heat and will break. The dial lamp in the grid circuit will glow only when there is excessive grid current. It will burn out when the grid current exceeds 60 milliamperes and thus acts as a fuse to protect the crystal.

Tubes used in oscillator circuits. The voltage produced by the oscillating crystal is weak. A type of oscillator tube must be used which will develop the greatest output from this weak grid voltage. The crystal operates best with high-mu power tubes such as the 6V6 or the 6L6. Either tube may be used in this circuit, since both have the same socket connections.

How to Operate It

Step 1. Turn on the heater current to the tube, and check connections.

Step 2. Turn on the B voltage. Observe the plate current. It will be about 20 milliamperes with 250 volts on the plate, unless the circuit is oscillating. Test for oscillation by touching the tank circuit with a lead pencil or a neon tube.

Step 3. Turn the condenser to tune the tank circuit to the frequency of the crystal. The tuning of this circuit is critical, and it will oscillate only when it is tuned to the frequency of the crystal. The plate current will drop sharply as the circuit begins to oscillate.

Turn off the plate voltage if the circuit cannot be made to oscillate by tuning the tank circuit. Check for poor connections or a burned out dial lamp.

Connect a direct current meter of 0 to 100 milliamperes in the positive plate lead.

Questions

1. Should high- or low-mu tubes be used with a crystal oscillator?
2. What is the disadvantage of using a high grid current on the crystal oscillator?

How It Works

When the cathode is heated, it throws off electrons. When the power is turned on, it makes the plate highly positive. The posi-

tive plate draws electrons from the space charge around the cathode, and plate current flows.

The plate tank circuit oscillates. When the surge of electrons from the tube plate reaches the tank coil, the electrons begin to oscillate through the tank circuit. See the explanation of how the Hartley oscillator works.

Feedback starts the crystal oscillating. At the instant that the B supply makes the plate positive, the grid becomes negative by condenser action (see Fig. 438). The highly positive plate draws electrons to the grid from plate *X* of the crystal holder. This makes plate *X* very positive. The condenser action between plate *X* and plate *Y* of the crystal holder causes electrons to be attracted to plate *Y*.

The unlike charges on *X* and *Y* cause the two plates to be attracted to each other. There is enough squeeze, or pressure, between the two plates to cause the crystal to flatten out slightly.

The crystal vibrates, or oscillates. Once set into vibration, the crystal will continue to oscillate as long as driving surges come from the tube. Current fed back through the capacity of the tube from the plate-tank circuit gives the crystal these driving surges. If these surges are too strong, they can build up vibrations in the crystal which will cause it to shatter.

As the crystal oscillates, it generates an alternating current between plates *X* and *Y* which, when timed properly with the current fed back through the tube, takes control of the action of the grid.

How the crystal controls frequency. The crystal will oscillate best at one frequency. Electron surges generated by the oscillation of the crystal reach the tube grid and time the surges of plate current which keep the tank circuit oscillating. If the tank circuit is tuned so that it oscillates at a frequency different from that of the crystal, the current fed back through the tube will reach the crystal out of time with the surges generated by the crystal. The two sets of surges oppose each other and will stop the oscillation of crystal. The tank circuit can also oscillate at multiples of the crystal frequency.

Purpose of the radio-frequency choke and grid leak. When the grid becomes positive, it collects electrons from the filament. These electrons flow back to the filament through the radio-fre-

quency choke and the grid leak. The grid-leak resistance keeps enough electrons on the grid to prevent plate current from flowing except at timed intervals. The grid is negative during most of the plate-current cycle. The radio-frequency choke prevents the rapid surges of alternating current generated by the oscillation of the crystal from shorting through the grid-leak resistor. Instead, it forces the surges on and off the grid.

Questions

1. Where is the voltage produced that keeps the crystal in oscillation?
2. Explain what happens if the plate tank circuit is tuned to a frequency different from that of the crystal.
3. What is the purpose of the radio-frequency choke?
4. What is the purpose of the grid leak?

PART 7: THE TRANSMITTER POWER SUPPLY

What voltage power supply is needed for transmitter experiments? If you will glance over the characteristics of the popular transmitting tubes used by radio amateurs and in low-powered commercial radio transmitters, you will find that the plate voltages run from about 350 volts for receiving type of tube, which may be used as an oscillator or amplifier, up to 3000 volts. The plate currents drawn by these transmitting tubes run from a few milliamperes up to 500 milliamperes.

You will find that many of the circuits described in this and later chapters will operate more effectively and will be more instructive if operated at higher voltages than you have so far used. A power supply which will deliver 400 volts and 200 milliamperes is a good compromise between the higher operating voltages commonly used with these tubes in actual transmitters and a value desirable for student use.

What parts are needed to build and wire the power supply? The power transformer should deliver 425 volts on either side of the center tap and have a current rating of 200 milliamperes. It should have a 5-volt secondary for the rectifier-tube filament. It should also have a 6.3-volt 10-ampere secondary for the oscillator- and amplifier-tube filaments.

You will need two oil-filled filter condensers, one 4-microfarad 600-volt and the other 8-microfarad 600-volt. Obtain a 15-henry

200-milliampere choke. The bleeder resistor should be 15,000 ohms with a 25-watt rating.

Wire the power supply as shown in Fig. 439.

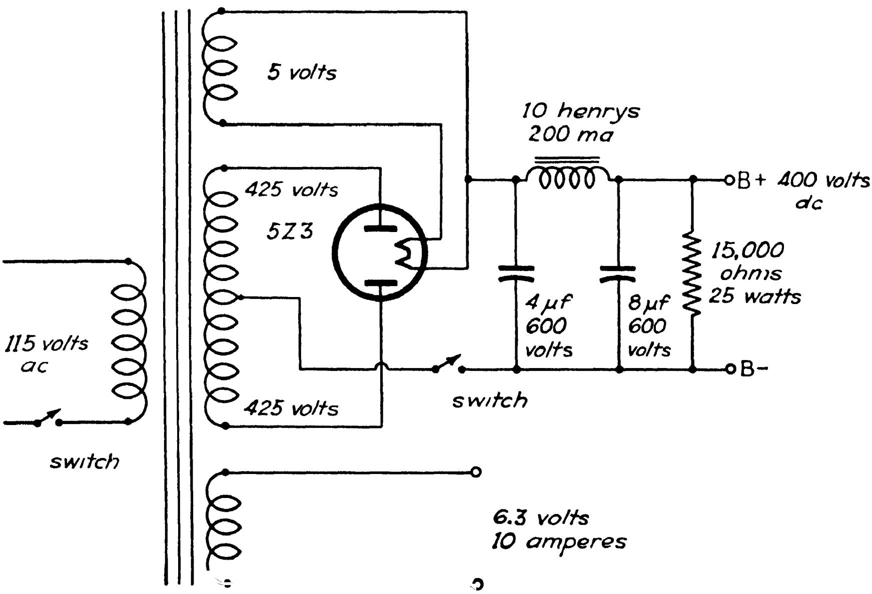


Fig. 439. The high voltage power supply. You may substitute the 5X4 for the 5Z3 rectifier tube if you wish to use an octal socket.

PART 8: THE RADIO-FREQUENCY POWER AMPLIFIER

While a radio-frequency amplifier operates on the same basic principle as the radio-frequency amplifier in a receiver, there are many practical differences. The radio-frequency power amplifier uses high plate voltage and heavy current flow. Either a triode or a pentode tube can be used. When a triode tube is used, the circuit must be neutralized to prevent unwanted feedback. Neutralization is not always required for the pentode. Some circuits work well without neutralization. A special source is needed to supply the high C bias required for class C amplifier operation.

There are several uses for the power amplifier. This power-amplifier circuit may be used for the final amplifier stage of a low-powered transmitter to build up the carrier wave to its maximum power before delivery to the antenna. It may also be used as a buffer amplifier. When used as a buffer amplifier, it is placed between the oscillator tube and the final amplifier to prevent vari-

ations in voltage, or power, in the final stage from affecting the frequency of the oscillator. A buffer amplifier is often used both ahead of and following a doubler amplifier in radiophone circuits.

Tubes to use. The 6C5 triode will work as an amplifier, but pentode tubes such as the 6F6 or the 6V6 are better for low-powered amplifiers. They will handle more power than will the triode. The beam power tubes will handle still more power.

Special transmitting power tubes are used in transmitter circuits. They are built with heavy filaments, or cathodes, to handle the heavy plate current. You will use the T20 triode and the 807, popular pentode power-amplifier tubes. You will use the 807 first in these experiments. Then you will learn the principles of neutralization by using the T20.

Power-handling capacity of a tube. The power a tube will handle is fundamentally determined by the amount of heat it can dissipate and the emission capability of the electron emitter. Heat is caused by the impact on the plate of electrons released by the filament, or cathode. The plate is sometimes blackened to radiate the heat Some tubes have carbon plates. Others use tantalum for the plate.

If the heat exceeds the limits of the tube, gas is driven out of the elements and the tube's operation is impaired. Most tubes are reaching the danger zone when the plates turn red.

How to Build and Wire It

Build this circuit on a large set board as shown in Fig. 440. The schematic diagram for an 807-pentode power amplifier is shown in Fig. 441. It is capacity coupled to the oscillator tank coil. Provide two clips, or binding posts, in the grid circuit for the grid-bias resistor. Also provide two clips for the grid-current meter.

How to Operate It

A. Adjust the oscillator

Step 1. Hook up the amplifier and the crystal oscillator (see Fig. 442).

Step 2. Connect the filament heaters to the power supply, and test the connection (see Fig. 442). *Turn off the power supply.*

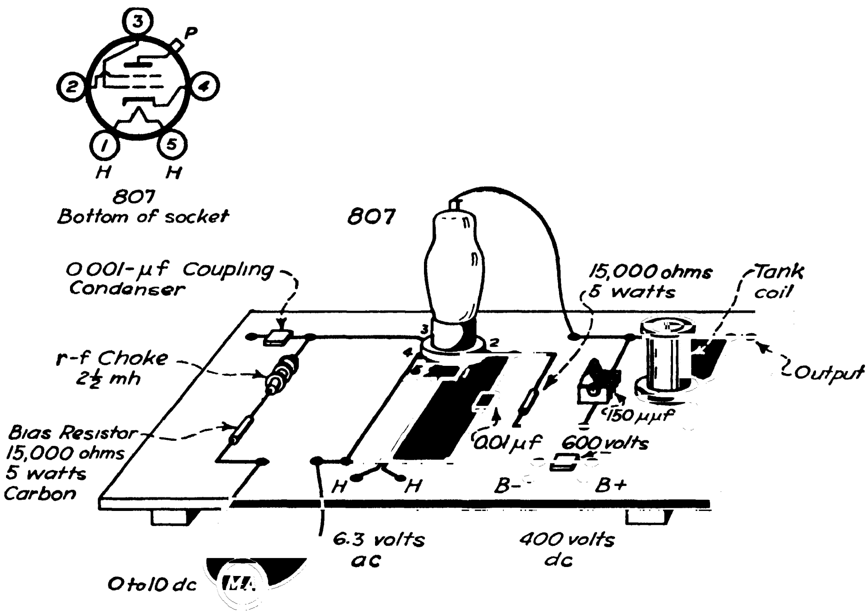


FIG. 440. The 807 radio-frequency power amplifier board layout.

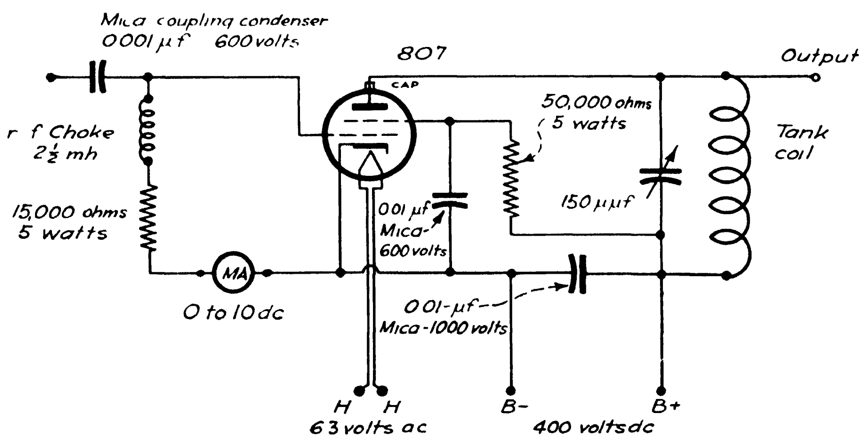


FIG. 441. The schematic wiring diagram of a pentode power amplifier.

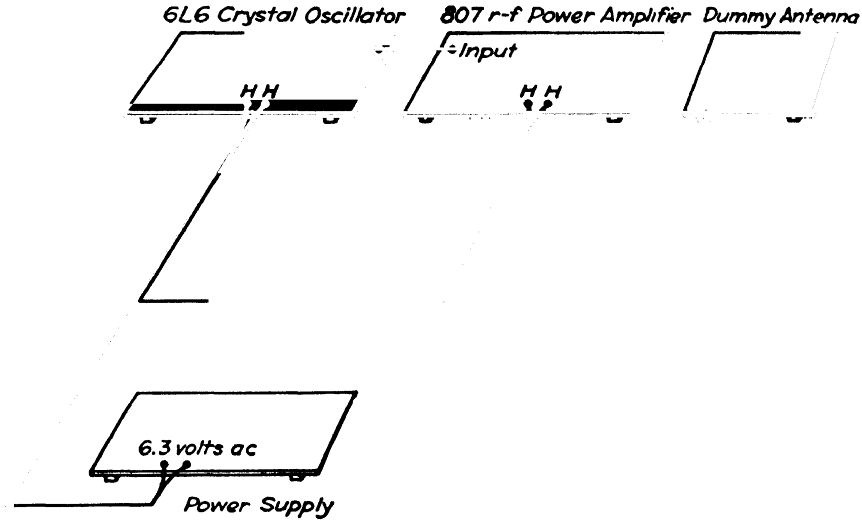


FIG. 442. Hook up the oscillator and amplifier by first connecting the wires to the heater circuits and to the power supply.

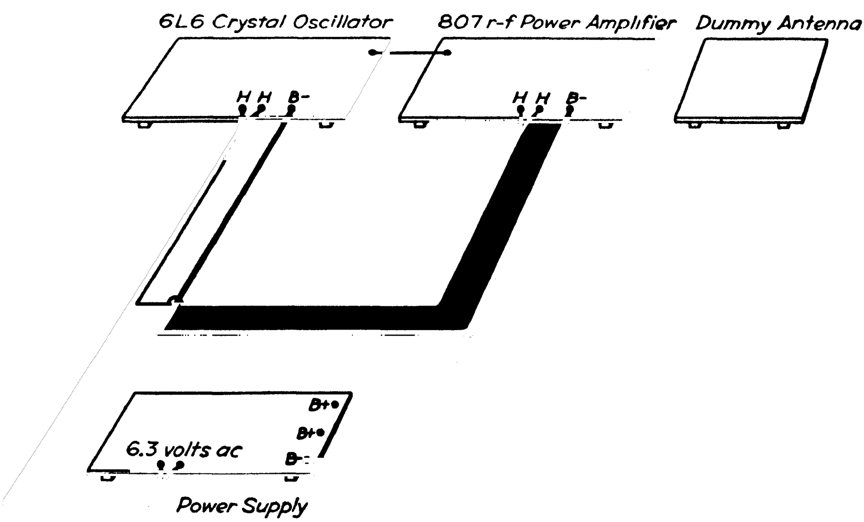


FIG. 443. Connect the B-minus wire as shown here.

Step 3. Connect a wire from the power supply to the B minus on both boards (see Fig. 443).

Step 4. Connect the B-plus wires to the oscillator board (see Fig. 444). Use about 250 volts. Connect the B power to the amplifier later. Attach a 0 to 100 direct-current milliammeter in the B-plus wire to the oscillator. Connect a 0 to 200 direct-current milliammeter in the B-plus lead to the 807 amplifier.

Step 5. Turn on the B power to the oscillator. Tune the oscillator for the meter dip which shows oscillation. Tune a few points

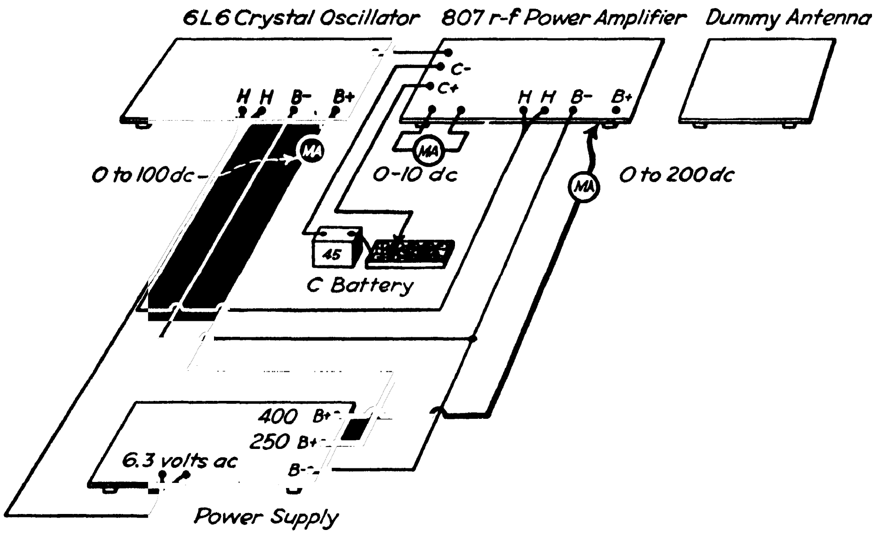


FIG. 444. Attach the meters and the B-plus connections to the power supply, and your set is ready to operate.

away from the oscillation point, so that the added load, when the amplifier is coupled to the oscillator, will not throw the oscillator out of oscillation. *Turn off the B power.*

B. Attach the amplifier to the oscillator

Step 1. Now couple the amplifier to the oscillator by attaching a wire from the plate end of the oscillator tank coil to the input terminal on the 807 amplifier board.

Attach a 50-volt C battery to the posts for the grid resistor. Be sure that the negative end of the C battery is connected toward the grid.

Note. If the C battery is made up of a 45-volt B battery tapped at 22.5 volts and ten 1.5-volt flashlight cells connected in series,

you will be able to adjust the bias voltage and watch its effect on the output of the amplifier. Start your experiment with the grid 50 volts negative.

Step 2. Attach 400 volts to the B-plus terminal of the amplifier.

Note. While higher voltage can be used on the amplifier to obtain a higher power output, the added danger of shock makes this undesirable. The set will operate satisfactorily at the lower voltage and be safer to handle.

Step 3. Turn on the B power. The grid meter should show a 3-milliampere grid current. If it does not read this value, adjust the grid-bias voltage until it reads 3 milliamperes.

Watch the plate-circuit meters to see that the oscillator is in oscillation and that the amplifier plate current is not excessive (over 100 milliamperes).

Step 4. Tune the amplifier for the lowest dip in plate current.

Note. If the C bias is removed from the amplifier tube, excessive plate current will flow and will damage the tube. The effect of high plate current is to overheat the plate, make the tube gassy, and possibly warp the tube elements enough to short them. This may short the power supply and cause further damage. You can prevent damage by watching the amplifier-plate meter and the tube plate. If the plate begins to get red, turn the set off and look for the cause of the trouble.

C. Attach the dummy-antenna load

Step 1. Couple the dummy antenna to the 807-power-amplifier tank coil. Set the pickup coil of the dummy antenna near the plate end of the tank coil.

Step 2. Retune the oscillator and amplifier for the current dip. More plate current now flows, because power is being absorbed by the dummy-antenna load.

Step 3. Adjust the 807 grid current. The grid current with 400 volts on the plate will be about 3 milliamperes.

When you couple the dummy antenna to the 807 amplifier, you load the circuit. The plate current will rise as well as the grid current. You can adjust the grid current by changing the C-bias voltage.

Step 4. Find the bias-resistor value. When you find the correct grid-bias voltage for the loaded amplifier, you can compute the value of the grid resistor by Ohm's law, $I = E/R$. You can read

the grid current I on the grid meter. You know E, the voltage of the C battery needed to produce the grid current. Work out the value of R from these two values.

Why It Works

Surges from the oscillator tank coil reach the amplifier through the coupling condenser. The grid, biased to twice cutoff, allows no plate current to flow during most of the grid cycle. When the grid is most positive, just at the peak of the cycle, a surge of plate current flows.

This strong surge reaches the tank coil, starts a surge through the coil, and then cuts off. The surge, or oscillation, continues through the tank coil, returns, and, just as it starts back, the next kick of plate current comes from the tube.

Class C amplification is used because powerful radio-frequency surges are produced very efficiently. Plate current flows only at the peak of the positive grid surge. During the rest of the cycle, the grid is so negative that no plate current flows. The tube thus runs cool. Therefore, with class C amplification, much more power can be handled by the same tube than could be handled by class A or class B amplification.

Class C Amplification

Amplifiers in radio transmitters have the job of developing radio-frequency power. Power, as you learned in an earlier chapter, is the product of voltage times current. Higher power is obtained by increasing the current, by increasing the voltage, or by increasing both the current and the voltage. Either the tube which handles high current must be large and expensive to dissipate heat or the circuit must be arranged so that current only flows during part of the cycle.

You know from your study of class B amplifiers that when plate current only flows during half the cycle the tube runs cooler than when current flows all of the time, as in the class A amplifier. You can use this same principle for the radio-frequency power amplifier. But now, since you intend to use high voltages and heavy currents, you should go even further than with the class B amplifier. You ought to let current flow through the tube for even less than a half cycle.

Class C amplifiers are biased to near twice cutoff. With this very high bias, the grid is so negative that only at the peak of the surge on the grid is there any plate current flowing through the tube (see Fig. 445).

Then, because the plate voltage is high, considerable current flows. For example, the maximum plate voltage on the 807 is

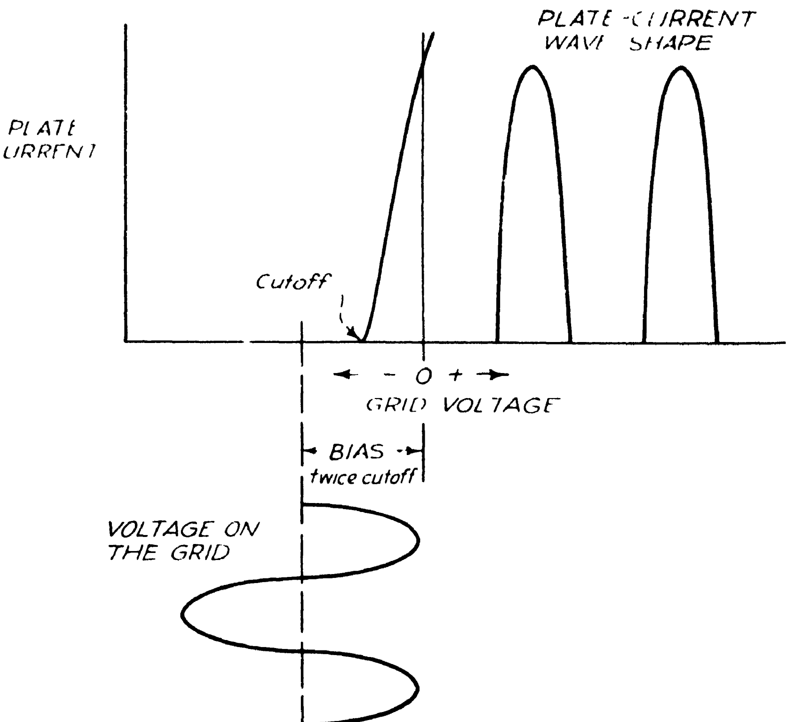


Fig. 445. The amplifier that is biased to twice cutoff for class C operation needs strong grid-driving voltage and delivers much power.

600 volts. The grid bias is minus 50 volts. At this plate voltage the plate current is 100 milliamperes. The power *input* is 60 watts. Class C bias is so efficient that about 40 watts of *output* is obtained at these conditions.

When the short but powerful surge of plate current occurs, it starts an oscillation of current through the tank circuit. Then the high grid bias cuts off the plate current, and no more current flows through the tube. Thus, since the heavy plate current flows for only a small fraction of the time, the tube will run cool.

The surge, started in the tank coil, continues for the rest of the complete oscillation because of the energy storage that takes place in both coil and condenser (see "How the Hartley Oscillator Works" in Part 1 of this chapter).

PART 9: HOW TO NEUTRALIZE THE POWER AMPLIFIER

Amplifier circuits which use a three-element tube, such as the T20, must be neutralized to prevent the generation of unwanted frequencies because of the feedback action of the tube elements. When the crystal oscillator is in operation, the amplifier will probably oscillate at the frequency to which the crystal oscillator is tuned, even though the amplifier is not neutralized. But should the crystal oscillator stop oscillating, the amplifier would go into self-oscillation at a frequency other than the crystal frequency. To prevent this unwanted oscillation, you must be sure the amplifier is properly neutralized.

Neutralization is needed on the amplifier. Neutralization must be used because there is enough capacity between the plate and grid of these tubes to feed back sufficient energy from the plate circuit to the grid circuit to set up oscillations which are not controlled by the oscillations from the preceding stage. The amplifier then acts somewhat like a self-excited tuned-plate tuned-grid oscillator.

The neutralized power-amplifier circuit is shown in the diagram in Figs. 446 and 447. Note the connection of the neutralizing condenser in this circuit.

Use a 20-micromicrofarad midget neutralizing condenser. This condenser must have about twice the capacity that is between the grid and the plate of the tube you are using. The interelectrode capacity is shown in a tube chart.

There are several methods of picking up the neutralizing voltage from the tank coil, but the method shown in the diagram (Fig. 447) is the most practical. Make the B-positive connection a few turns from the end of the tank coil with a clip, so that the connection can easily be changed.

How to Operate the Set

Step 1. Disconnect the B-positive lead from the T20 amplifier stage.

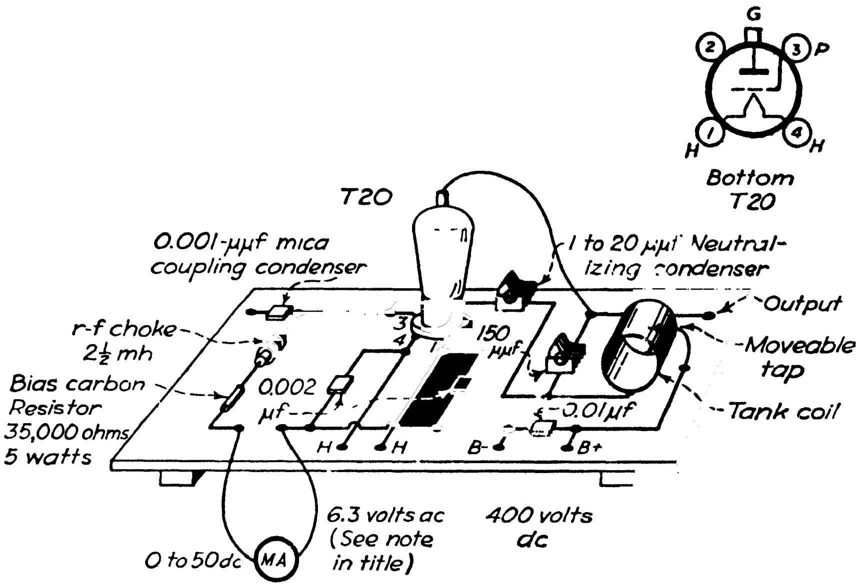


FIG. 446. Board layout of parts for the T20-neutralized power amplifier. Note that while the T20 requires 7.5 volts alternating-current for the filament supply, you can use 6.3 volts alternating-current for your experiment with this tube. The tube will demonstrate the principles of amplification and neutralization but will not be operating up to its full capacity.

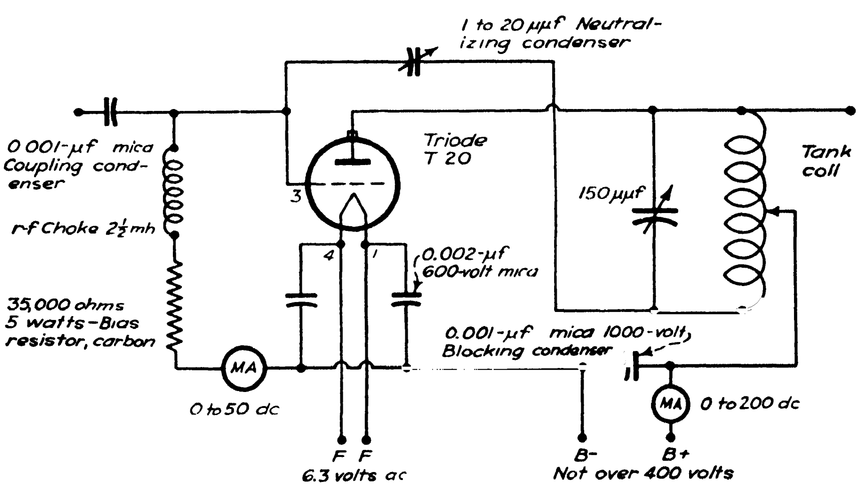


FIG. 447. Schematic wiring diagram of the neutralized power amplifier. Note that the amplifier is operated at reduced filament voltage.

Step 2. Heat the cathode and filament of the oscillator and amplifier tubes.

Step 3. Connect the B-positive tap a few turns from the end of the plate tank coil opposite to the connection to the tube plate.

Step 4. Touch the base of a neon tube to the plate end of the amplifier tank coil. If the tube glows, the tank circuit is oscillating and must be neutralized.

Step 5. Turn the neutralizing condenser *N* until the glow in the neon tube disappears. At this condenser setting, the capacity of the neutralizing condenser and the capacity between the grid and plate of the amplifier tube are equal, and the set is neutralized. You may have to move the position of the B-positive tap if the neon-tube glow cannot be eliminated by adjusting the neutralizing condenser.

Step 6. Attach the B-positive lead.

Questions

1. Why must these radio-frequency amplifiers be neutralized?
2. How should the size of the neutralizing condenser compare with the capacity between the grid and the plate of the tube?
3. How can you tell when a stage is neutralized?

Why It Works

When the set is in operation, regular surges come into this circuit over wire *D* (Fig. 448) from the crystal oscillator.

Now follow a surge as it arrives at the tube grid, and watch its effect on the circuit.

The Action of an Amplifier without Neutralization

Effect of the excitation surge. When a surge from the oscillator stage drives electrons onto grid *A* of the amplifier tube, it makes the grid negative and stops the flow of current to the plate.

The tank current surge. While the grid is negative, the oscillating current in the tank circuit surges as shown in Fig. 448. Some electrons are forced onto the plate of tube *B*, because there is now an electron pressure on the plate end of the tank coil. This makes the plate less positive.

The plate will repel electrons from the grid. This interferes with the strength of the surges coming from the oscillator to the amplifier grid which we want to control the tank-circuit surges.

The tank-circuit surges reverse. When the surge in the tank coil reverses, electrons are drawn off the tube plate, making it more positive than it was. The positive plate pulls electrons to the grid, which should now be more negative, again interfering with the strength of the driving surges from the oscillator.

The effect of the interfering charges on the grid is to set up unwanted and interfering frequencies. It is this unwanted frequency which lights up the lamp you use to test neutralization with the B power turned off.

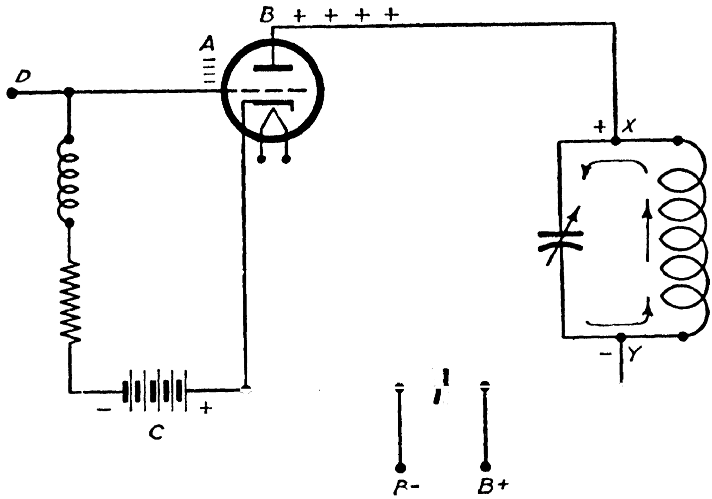


FIG. 448. Without neutralization, the surges in the tank circuit drive electrons onto the plate and cause feedback through the tube.

How neutralization stops unwanted surges. The neutralizing condenser is connected as shown in Fig. 449, so that electrons are forced onto it at the same time that they are forced onto *B*. Why does this happen?

When the tank-current surge flows through the upper part of the coil, it induces a current in the opposite direction in the lower part of the coil.

Electrons from the induced current flow to the grid by way of the neutralizing condenser *N*. They reach the grid in time to oppose electrons reaching plate *B* from the upper part of the tank circuit.

By adjusting the position of the B-plus tap on the coil and by

properly setting the neutralizing condenser, the same number of electrons reach the grid as are on the plate. Since the voltage on the grid is equal and opposite to the voltage on the plate, no feed-back occurs through the tube. The amplifier is neutralized, and the surges from the oscillator can now drive the amplifier without interference.

The B-positive lead is connected to the ground (B minus) by a small condenser. The point on the coil where B positive taps in is always at zero, or ground, potential as far as the radio-frequency

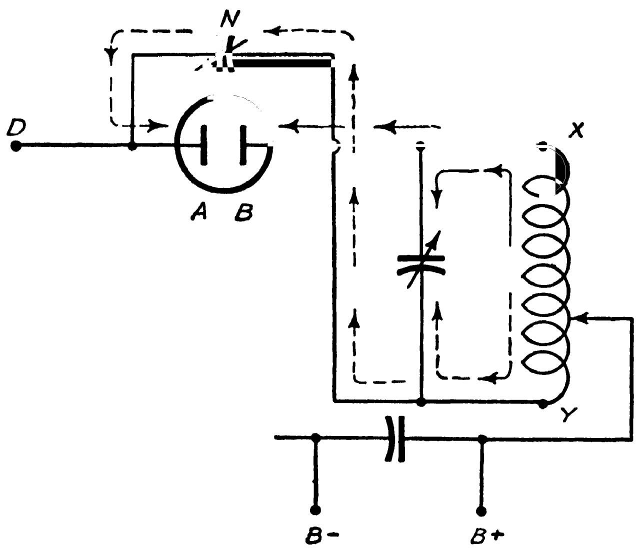


FIG. 449. The neutralizing condenser, connected as shown here, provides surges of proper strength and timing to prevent feedback through the tube.

current is concerned, because any voltage which tends to develop here is by-passed through the condenser to the ground. The condenser, however, keeps the direct current of the B positive and B negative separated (see Fig. 447).

Questions

1. What effect does the capacity between the grid and the plate have upon the operation of a radio-frequency amplifier?

2. When the *X* end of the tank coil is positive, what effect would the grid have upon the feed line *D* if the amplifier were not neutralized (see Fig. 448)?

3. If plate *A* of the condenser had a ready supply of electrons, would it also try to pull electrons from line *D*?

4. Explain how the *Y* end of the tank coil could supply the needed electrons to plate *A*.

5. What is the purpose of the neutralizing condenser?

6. Why is the B-positive lead not attached directly to the *Y* end of the tank coil?

PART 10: THE FREQUENCY-DOUBLER CIRCUIT

A crystal for the higher frequencies must be cut very thin. Such a crystal is easy to break if it is handled or if it is used in a circuit that is improperly operated. Crystals ground for the 80-meter bands are rugged and thick enough for ordinary experimental and operating use.

You can operate on the higher frequencies with crystal control, as is done in amateur transmitters and in frequency-modulated transmitters, by using frequency doublers, triplers, or quadruplers. Thus 40-meter frequency can now be amplified just as could the 80-meter frequency. Several stages of amplification can be added at the higher frequency.

Question

What are some advantages to amateurs of using frequency-doubler circuits?

How to Build and Wire the Set

Place the socket for the tube and for the plate tank coil and condenser in the position shown in Fig. 450. Use 600-volt mica condensers for the coupling and the blocking condensers in the plate circuit (see Figs. 450 and 451). The coupling condenser must stand the plate voltage of the preceding stage. Its voltage rating should be twice the plate voltage.

Tube. Use an 807 power tube.

Bias. Use either a C battery or a 30,000-ohm noninductive resistor connected to the grid through a radio-frequency choke to get the proper bias. The bias voltage must be twice the voltage needed for cutoff.

Choke. Use a 2½-microhenry radio-frequency choke in this circuit. The type of choke used in receivers can be used in sets of up to 50 watts input.

Coil. The coil will have half as many turns as the coil you wound for the crystal oscillator.

How to Operate It

Step 1. Turn on the heater current for the oscillator and doubler.

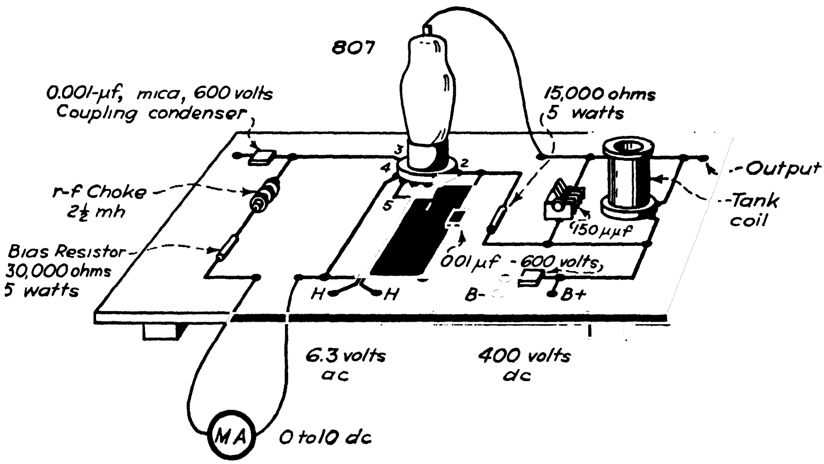


FIG. 450. This is the board layout for the frequency-doubler circuit.

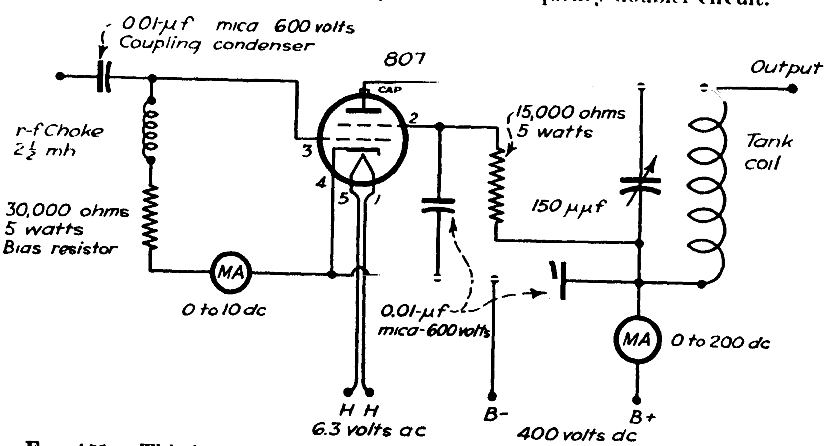


FIG. 451. This is the schematic diagram for the frequency-doubler circuit.

Step 2. Turn on the B voltage after the cathodes have had time to heat.

Step 3. Adjust the tuning condenser until the crystal stage is in oscillation.

Step 4. Tune the doubler circuit to twice the frequency of the oscillator. Check with an absorption type of wavemeter (which

responds only to the fundamental frequency and will not respond to harmonics).

When tuned off frequency, the doubler will draw a heavy plate current.

You can tune the set so that it doubles twice (quadruples), as from 80 meters to 20 meters, in the same stage. But if this is done, the output of the circuit is very low and its efficiency poor.

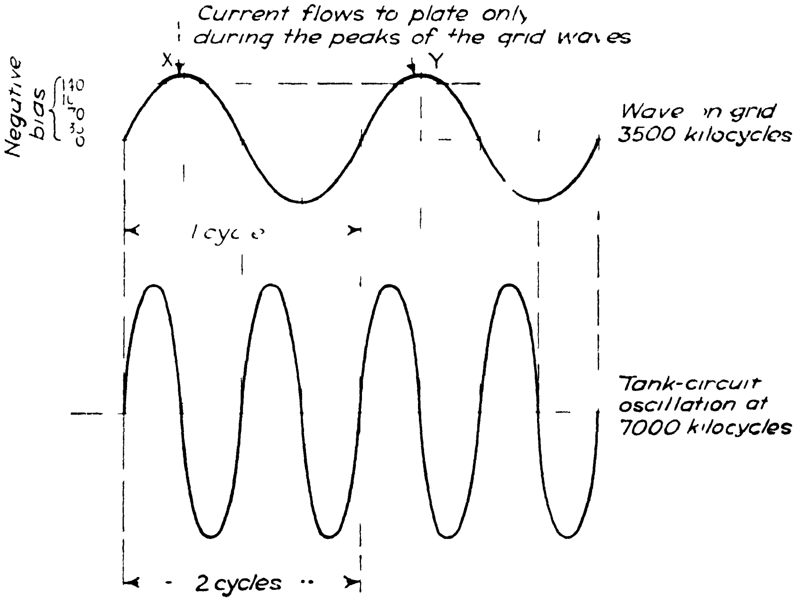


FIG. 452. The wave picture that shows how the frequency doubler works

Caution. The grid bias, when a resistor is used, is caused by the current from the oscillator (the excitation voltage to the doubler grid). If the oscillator is turned off, the grid will become positive enough to draw current. Heavy plate current will flow and the doubler tube may possibly be injured

For this reason, the oscillator stage is not keyed alone in telegraphy operation.

How It Works

The grid of the doubler tube is excited by electron surges from the oscillator circuit through the coupling condenser (see Fig. 451). The voltage applied to the grid of the tube is called the *grid excitation*.

The wave-form picture in Fig. 452 shows the current from the previous stage that is on the grid of the doubler tube. (The grid of the doubler tube is biased to about twice cutoff.) Current will flow in the plate circuit of the doubler tube only when the surges from the previous stage become positive enough to overcome the grid bias (see *X* and *Y*, Fig. 452).

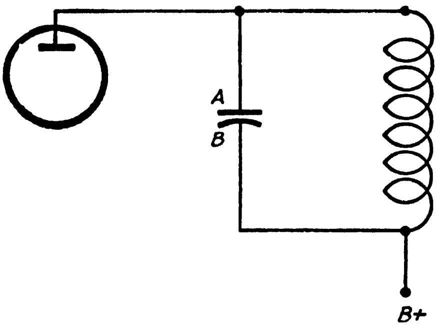


FIG. 453. Use this circuit to study the surges that produce neutralization.

The doubler tank circuit is tuned to twice the frequency of the oscillator. When current flows through the doubler plate circuit, it starts a surge in the tank circuit (see Fig. 453). This current surges through the tank coil to side *B* of the condenser and returns through the tank coil to side *A*. It then coasts back again through the coil to *B*, then back to *A*.

The moment the surges from *A* start toward *B* again, the grid becomes positive (shown on the wave picture at *X*, Fig. 452), allows current to flow for an instant through the tube, and gives the current surge a push through the tank circuit. Again the tank circuit coasts through two complete oscillations before the grid becomes positive enough (at *Y*, Fig. 452), to give the plate tank another push.

The frequency of the doubler tank circuit is twice the frequency of the surges of the grid on this circuit. This doubles the oscillator frequency.

There is some loss of energy during this coasting. But this loss is of far less importance than the expensive apparatus this circuit replaces. Any loss in the doubler circuit is made up in the amplifying circuits which precede and follow the doubler.

Questions

1. What is the disadvantage of doubling the frequency twice in the same tube?
2. What might cause the plate of the tube to get red-hot?
3. Why is the oscillator stage in a doubler circuit never keyed?
4. How much of the time is current flowing in the plate circuit of the doubler tube?

PART 11: THE PUSH-PULL FINAL POWER AMPLIFIER

The single-tube amplifier is used both in buffer circuits and sometimes in the final amplifier stage of the transmitter. But if much power is applied to this circuit by using high B voltage, the tube heats and does not operate efficiently. An improved circuit which uses two tubes operates in push-pull. The push-pull circuit has many advantages. It can use a higher B voltage and it will

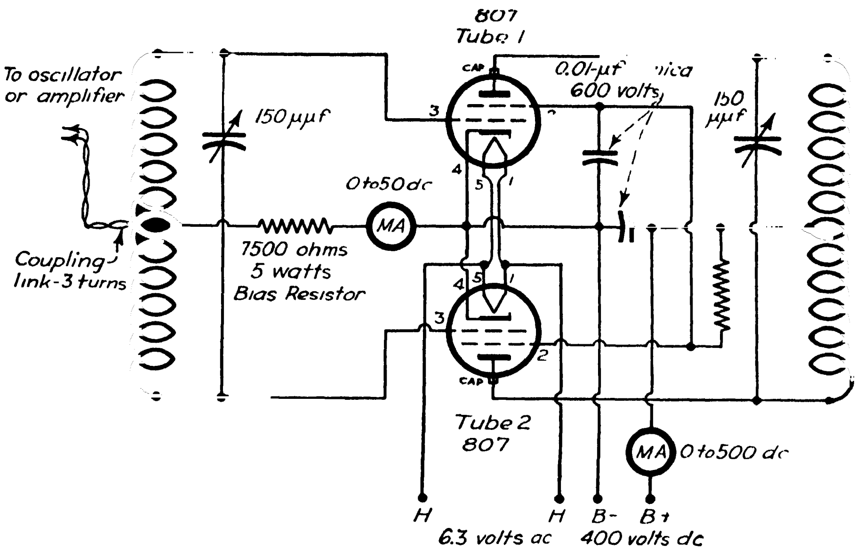


Fig. 454. The schematic circuit diagram for the push-pull radio-frequency power amplifier.

develop more power than can a single tube, and the two tubes will not overheat.

Some power is lost in a one-tube amplifier by energy by-passing to the ground through the capacity between the grid and the filament. The capacities between the grid and the filament of the two tubes in this push-pull circuit are in series (see Fig. 454). This lowers the capacity to ground so that the radio-frequency energy loss is reduced. The second harmonic generated in single-tube amplifier circuits is canceled out in the push-pull circuit. Other advantages of the push-pull amplifier circuit when used at high frequency will be taken up later.

The push-pull circuit is generally used in the final amplifier stage.

It is more often used to develop high power output in the final stage than in the stages ahead of the final amplifier.

Question

Make a list of advantages of the push-pull circuits over the one-tube amplifier.

How to Build and Wire the Set

Build this amplifier on a larger board. Build two identical tank coils (see Fig. 455). These coils are the same as those described for the crystal oscillator in Part 6 of this chapter. This circuit is a tuned-plate tuned-grid circuit, and so there must be a grid tank

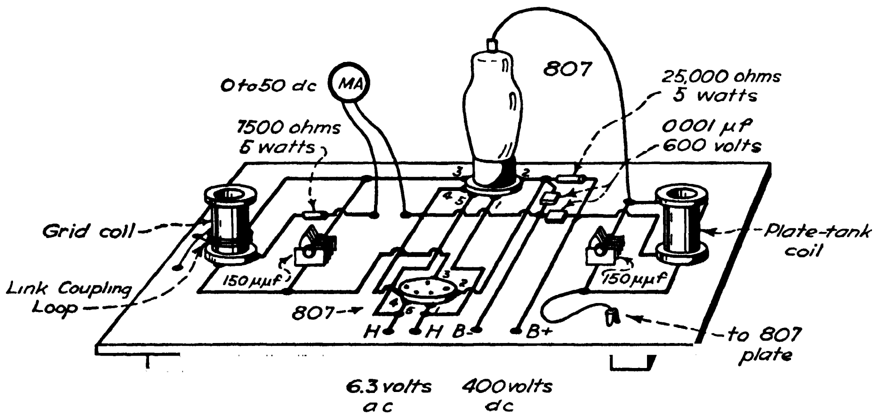


FIG. 455. This is the board layout of the push-pull power amplifier.

circuit and a plate tank circuit. Provide two sockets for the 807 tubes. Series feed is used in this circuit.

The plate blocking condenser and the by-pass condenser are all 600-volt mica condensers. Use a 7500-ohm 5-watt bias resistor.

How to Couple between Stages

A new coupling method between stages must be used for the push-pull circuit. In the earlier amplifier circuits that you have studied, you could use a coupling condenser. But the tuned-grid circuit of the push-pull amplifier can be coupled more effectively by some form of inductive coupling. A convenient scheme is to use a coupling link.

The coupling coils may be three turns of No. 18 insulated hookup wire. Make the loop about ½ inch larger in diameter than the

tank coil of your amplifier (see Fig. 456). Twisted wires of the same size connect the two links. The length of the connecting wires is not important.

How to Hook Up the Amplifier

Step 1. Set the 807 radio-frequency amplifier near the push-pull 807 amplifier board. Attach the coupling links.

Step 2. Adjust the links so that both are near the base of the coils.

Step 3. Attach the heater and B-power wires.

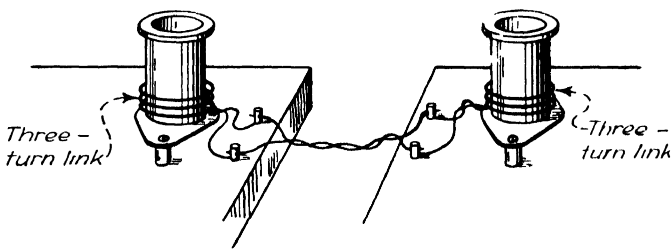


FIG. 456. Link coupling. The three-turn links may be moved up or down the coil by bending the supporting wires.

How to Operate the Amplifier

A. Tune the oscillator and amplifier

Step 1. Turn on the heaters.

Step 2. When the oscillator is tuned to the proper frequency, enough current reaches the grid of the power-amplifier tube from the previous amplifier stage to provide excitation.

B. Tune the push-pull amplifier

Step 1. Tune the grid circuit until you get the maximum reading of the grid meter.

Step 2. Tune the plate circuit for the lowest dip of the plate meter.

C. Couple the amplifier to a board

Step 1. Couple the dummy antenna to the amplifier. Figure out the size of lamp you will need in the dummy antenna from the plate voltage and the plate current.

Step 2. Tune the dummy antenna.

Step 3. Retune the grid and plate of the amplifier.

Step 4. Adjust the coupling of the dummy antenna to the plate tank coil to load the tubes to their rated plate current as shown in the tube handbook (200 milliamperes for the 807 tube). Since the tubes in this circuit are running at less than their rated voltage, the plate current will be less than is shown in the tube manual. You can adjust for maximum plate current safely.

Step 5. Adjust the coupling link so that the grid excitation is 10 milliamperes. You adjust the grid excitation by moving the link toward the top of the amplifier plate coil to increase excitation or toward the bottom to decrease excitation.

Why It Works

Current surges from the oscillator or from the amplifier stage set the grid tank coil in oscillation. When the electrons surge to the grid of tube 1, they make the grid so negative that no current flows. At the same instant, the grid of tube 2 becomes positive enough to allow current to flow through the tube at the peak of the surge.

In the class *C* amplifier the grid is biased by means of a bias resistor to twice cutoff. This means that the grid is so negative that it will only allow current to flow through the tube at the peak of the excitation wave, or surge.

Compare the push-pull circuit and the single-tube amplifier. Let us examine the plate tank circuit (see Fig. 454). A plate is connected at each end of the push-pull tank circuit, while in the single-tube amplifier a plate is connected only at one end of the tank circuit. The single-tube tank circuit gets a push from the plate once every two surges, while the push-pull tank circuit receives a push from the plate at each end of the circuit during each surge. It is easy to see why the push-pull circuit develops so much more power without overloading the tubes than does a single-tube amplifier.

The efficiency of the power oscillator. The push-pull circuit we have just described is very efficient and the tube plates remain cool. This is because the average current between the filament and the plate is low. The current flows through the plate circuit of each tube only at the instant when the maximum current of the positive surge is on the grid. This means that during most of the cycle the tube is coasting, that is, no current is flowing through the tubes.

Questions

1. What type of coupling is used for push-pull circuits?

2. Make a schematic diagram of the coupling for a push-pull circuit, and explain how it works.

3. How much bias is used in class C amplification?

4. Why do the plates remain cool in a push-pull circuit?

Technical Terms

dummy antenna—A tuned circuit, consisting of a pickup coil, a tuning condenser, and a lamp, which may be coupled to an oscillator or an amplifier circuit in the place of an antenna while the performance of the circuit is being tested.

excitation—The voltage on the grid of an oscillator tube is called the grid excitation or the exciting voltage.

frequency meter—A tuned circuit used to test the frequency on which a circuit is oscillating. The tuning condenser may be calibrated to read the frequency, or a calibration curve may be drawn.

load—Something which absorbs power. A dummy antenna acts as a load to absorb power from an oscillating circuit. An amplifier may be the load coupled to an oscillator or to another amplifier.

oscillator—A tube and circuit used to generate radio-frequency oscillations.

series feed—A circuit in which the B power supply is connected in series with the tube plate, the tank circuit, and the cathode.

shunt, or parallel, feed—A circuit in which the B power is connected to the plate through a radio-frequency choke in parallel with the tank circuit.

stability—The opreation of an oscillator on one fixed frequency.

tank circuit—The oscillating circuit, which consists of a tank coil and a variable condenser.

CHAPTER 21

RADIO-TELEGRAPH TRANSMITTERS

The radio-frequency oscillators that you have studied are basically the same as the oscillator circuit you saw on the visit to the broadcast transmitter described in Chapter 1 of this book. The same is true of the basic amplifier circuits. If you browse through Chapter 1 again, you will recall that one cabinet of the transmitter enclosed an oscillator and an amplifier and that following cabinets enclosed more powerful amplifiers.

Now, if you were to visit the radio room of a ship or if you were to examine the radio equipment of a transoceanic clipper, you would find radio-telegraph sets along with radio-telephone sets.

Radio-telegraph code. These radio-telegraph sets are used to handle important commercial messages that are difficult to transmit by voice through static and other disturbances. Try to tell a person at the other end of a noisy telephone line a name or several numbers, and you can understand the difficulty of sending important messages or orders by voice. Sounds like *D*, *B*, *C*, and *G* are easy to confuse. But if radio code is used, these messages are transmitted successfully over long distances.

Code can be heard and used much farther than can the voice. You have often tuned your broadcast receiver to a hiss which you knew was a broadcast-station carrier wave, but you could hear no voice at all.

By putting a key in the circuit, it is possible to make and break the carrier wave into the dots and dashes of radio code. You may do this only if you hold an operator's and a station's license, as explained later in this chapter.

The radio amateur. The American and foreign radio amateur (the so-called *ham*) is well known. Many people, young and old, men and women, have taken their soldering irons and pliers in hand and have built their own equipment, learned the code, and

passed the technical examinations, and they now enjoy the pleasure of "hamming." They build and rebuild their sets, trying to get the best possible results from them. They try out queer circuits and odd ideas. They have established and maintained a multitude of radio "nets" over which they carry on a constant stream of amateur message traffic as well as plain "ham chatter." In times of emergency and disaster, they have stepped in to provide communication between the stricken area and the outside world. From their ranks have come such men as Armstrong, the inventor of the superheterodyne circuit and a frequency-modulation system, and Farnsworth, who has contributed outstanding developments in television, to mention only two out of hundreds.

From their ranks have come in two great wars the operators, technicians, teachers, engineers, and research men who did much to give our forces the best radio equipment in the world and an unparalleled group of operators.

In this chapter you will learn about the following things:

Part 1: What Is a Radio-telegraph Transmitter?
Part 2: The Simplest Transmitter—The Crystal Oscillator
Part 3: The Oscillator-Amplifier Transmitter
Part 4: Other Transmitter-circuit Combinations
Part 5: The Antenna Coupling
Part 6: Revisiting a Broadcasting Station

PART 1: WHAT IS A RADIO-TELEGRAPH TRANSMITTER?

Briefly, a simple radio-telegraph transmitter consists of an oscillator coupled to an antenna, a key, and a power supply. Many an amateur has operated such a set until he could afford a better, more powerful transmitter.

By adding radio-frequency power amplifiers and heavier power supplies, you can increase the power output of the transmitter. The same equipment, with a public-address unit and a modulation circuit, explained in the next chapter, can be used as a radiotelephone transmitter.

You have studied a number of oscillator circuits and their operating characteristics and peculiarities. You have also learned how to use power amplifiers and doublers. You have learned how to get a fixed frequency with the crystal oscillator, and you have learned methods of setting an oscillator to a specified frequency

with the absorption type of frequency meter. You will learn in this chapter how to arrange these circuits as transmitters.

Notice how these circuits are keyed, which stages are neutralized, and the hints for refining these circuits to make them better transmitters. Notice the operating precautions. When you study the keying circuits, notice where keying should be done.

Several groups, or bands, of frequencies are set aside for amateur use by the Federal government. Your transmitter may operate in these bands of frequencies only after you have passed the government license examination and have been granted an amateur operator's license and a station license. The examination consists of a test of your ability to send and receive the continental Morse code at the rate of 13 words per minute and to answer a set of questions which cover the principles and operation of amateur transmitting equipment and the laws and regulations which you must know and observe while operating.

PART 2: THE SIMPLEST TRANSMITTER—THE CRYSTAL OSCILLATOR

Probably the easiest transmitter to set up is the one that uses only a crystal oscillator and a power supply. When keyed and connected to an antenna, it makes a low-powered transmitter for a beginner but undesirable harmonics may be transmitted.

While the self-excited Hartley and the tuned-plate tuned-grid oscillator will work as transmitters, you are advised against using them, because they are difficult to keep on frequency.

You will find that the crystal oscillator is much more satisfactory and easy to adjust and operate.

How to Hook Up a Transmitter

Step 1. Connect the crystal oscillator described in Chapter 9 to the power supply, as in Fig. 457. The schematic circuit is shown in Fig. 458.

B voltage. The B voltage you can use for the transmitter depends on the tube you are using. A 6F6 or a 6V6 will handle up to 350 volts, while a 6L6 can handle 400 volts. Higher plate voltages may cause damage to the crystal.

The antenna. The diagram of the crystal hookup in Figs. 457 and 458 shows an end-fed antenna. The antenna must be cut to the proper length for the amateur band on which you wish to

operate. You would cut an 80-meter antenna 132 feet long from the far end of the antenna to the connection to the tank coil.

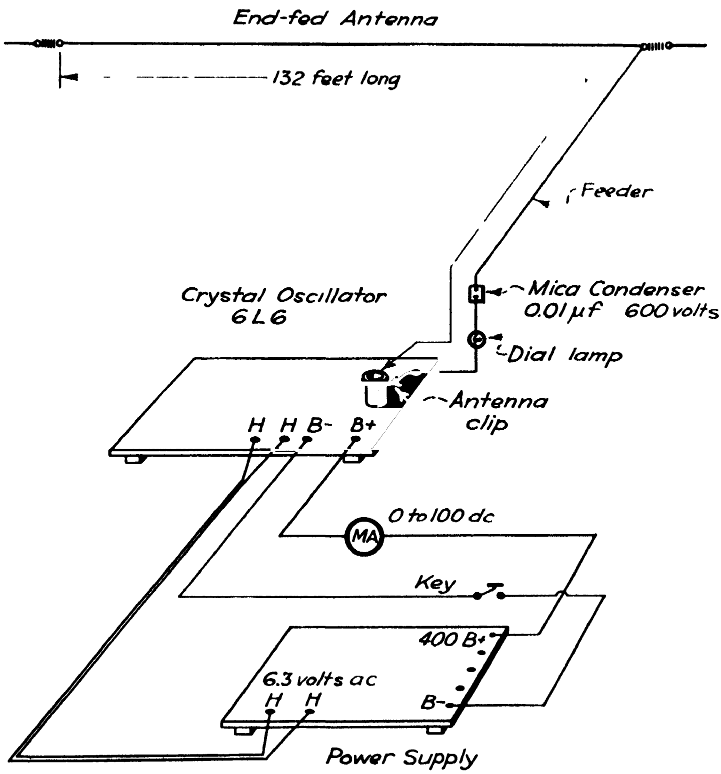


FIG. 457. A simple transmitter. Hook up a power supply to a crystal oscillator. Attach a key in the B-minus lead, attach to an antenna, and you have a low-powered transmitter.

80 meters × 39.4 inches = 3152.0 inches

$$\frac{3152}{12} = 262.75 \text{ feet}$$ – the length of a full-wave antenna

$$\frac{262.75}{2} = 131.38 \text{ feet}$$ the length of a half-wave antenna

Connect a telegraph key in the B-minus lead (see Fig. 458). Connect a 0 to 100 direct-current milliammeter in the B-plus wire.

Step 2. Plug in an 80-meter crystal. Its frequency may be between 3500 kilocycles and 4000 kilocycles.

Step 3. Couple the feeder wire from the antenna to the tank coil. Attach a 0.01-microfarad 600-volt mica condenser in the

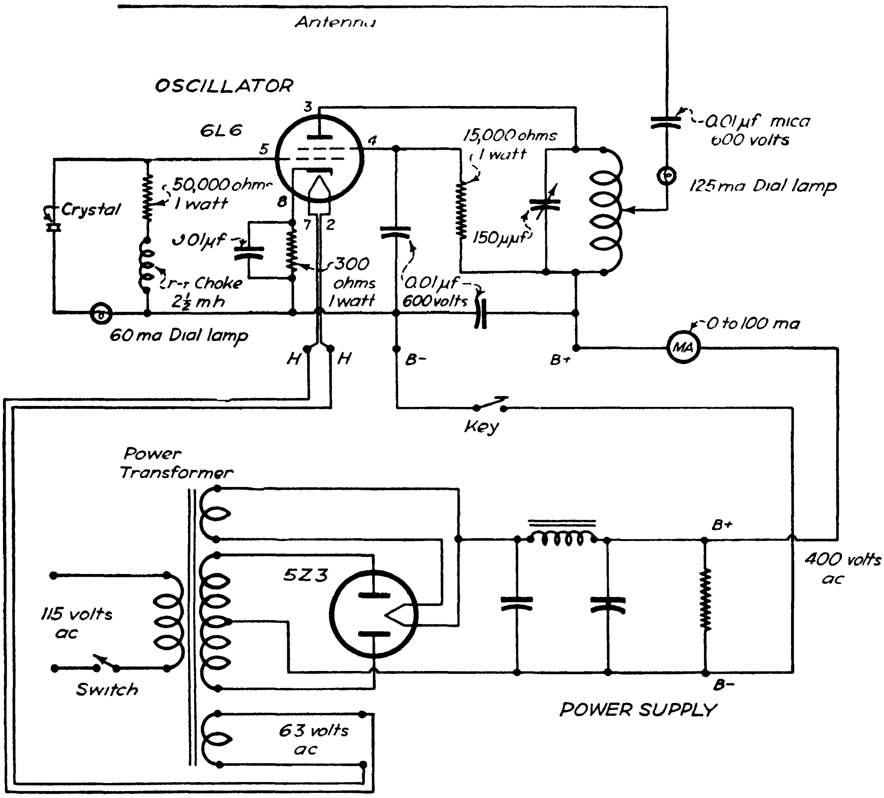


FIG. 458. The circuit for the simple transmitter.

feeder wire to avoid shocks, and attach a pilot light for indicating the power put into the antenna.

How to Operate It

Step 1. Turn on the power supply.

Step 2. Disconnect the antenna clip. Press the key and turn the tank condenser until the meter dip shows that the set is tuned to the crystal frequency. (Reread the section on how to operate the crystal oscillator in Part 6 of Chapter 20.)

Step 3. Attach the antenna clip about $\frac{2}{3}$ of the way up the coil. Again tune for meter dip. Since more plate current is flowing, the lowest point of the dip will be higher than before because of the power drawn by the antenna. The farther toward the plate end of the coil you set the clip, the greater will be the output of the set. You will find a spot on the coil by trial where you will get the greatest output for the antenna you are using.

You can touch the base of a neon tube to the antenna at *X*. It will glow if radio-frequency surges are present in the antenna. The brightness of its glow is also a rough indication of the output of the set.

You can also tell by the brightness of the dial light how much power is being put into the antenna.

Range of the Transmitter

Most amateur operators soon ask how far their sets will send. This is a hard question to answer. On a clear, cold night when no one else is on the air, this little set will send out a signal that can be heard thousands of miles away. But on an evening when the air is crowded by a host of other signals. your signal may not be heard across town.

The power output of your set depends on how well you have it tuned and how well you have set up your antenna. A well-placed antenna, well insulated and properly adjusted, will put out a good signal. Many experienced amateurs claim that there are two ways to work DX (distant stations). One is to have a "rock crusher" (a powerful set with a strong signal); the other, to have a lower powered, highly efficient set that is effectively operated.

Questions

1. Why is the crystal oscillator preferred to the Hartley or tuned-plate tuned-grid circuits?

2. What is the danger of using too high a plate voltage on your transmitter?

3. How can you tell when the set is tuned to the frequency of the crystal?

PART 3: THE OSCILLATOR-AMPLIFIER TRANSMITTER

This set is sometimes called the *master-oscillator power amplifier.* The amplifier acts as a buffer between the antenna and the oscillator, and there is less likelihood of frequency shifting than if you use a single oscillator. This circuit has the advantage of putting a

stronger and more stable signal on the air than will the single-oscillator stage.

How to Hook Up the Transmitter

Step 1. Hook up the crystal oscillator to the 807 power amplifier (see Figs. 459 and 460). Couple the two circuits by means of a condenser, as shown in these diagrams.

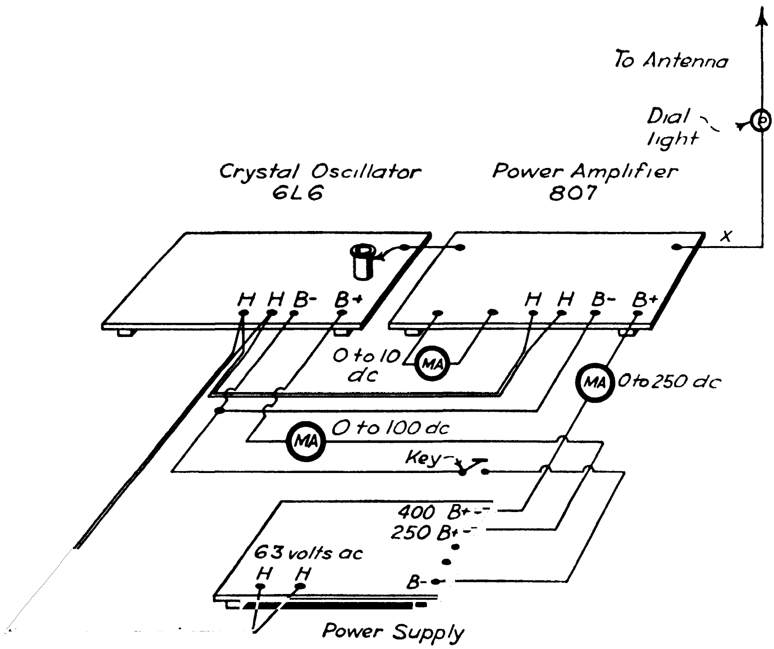


FIG. 459. A more powerful transmitter. Add an 807 power amplifier and your signal will be much more powerful than when only an oscillator is used.

Step 2. Attach the power supply. Connect about 250 volts on the oscillator and 400 volts on the plate of the 807. Either attach a direct-current milliammeter in each plate lead or place a closed-circuit jack in each B-plus lead, so that one meter can be used for tuning each stage.

Step 3. Couple the antenna to the tank coil of the 807 amplifier. See Part 5 of this chapter.

Step 4. Attach the key in the B-minus lead. This circuit shows that the key is placed in the B-minus lead so that the key will control the plate voltage to both the oscillator and the amplifier. This keys both oscillator and amplifier together. This must be done so

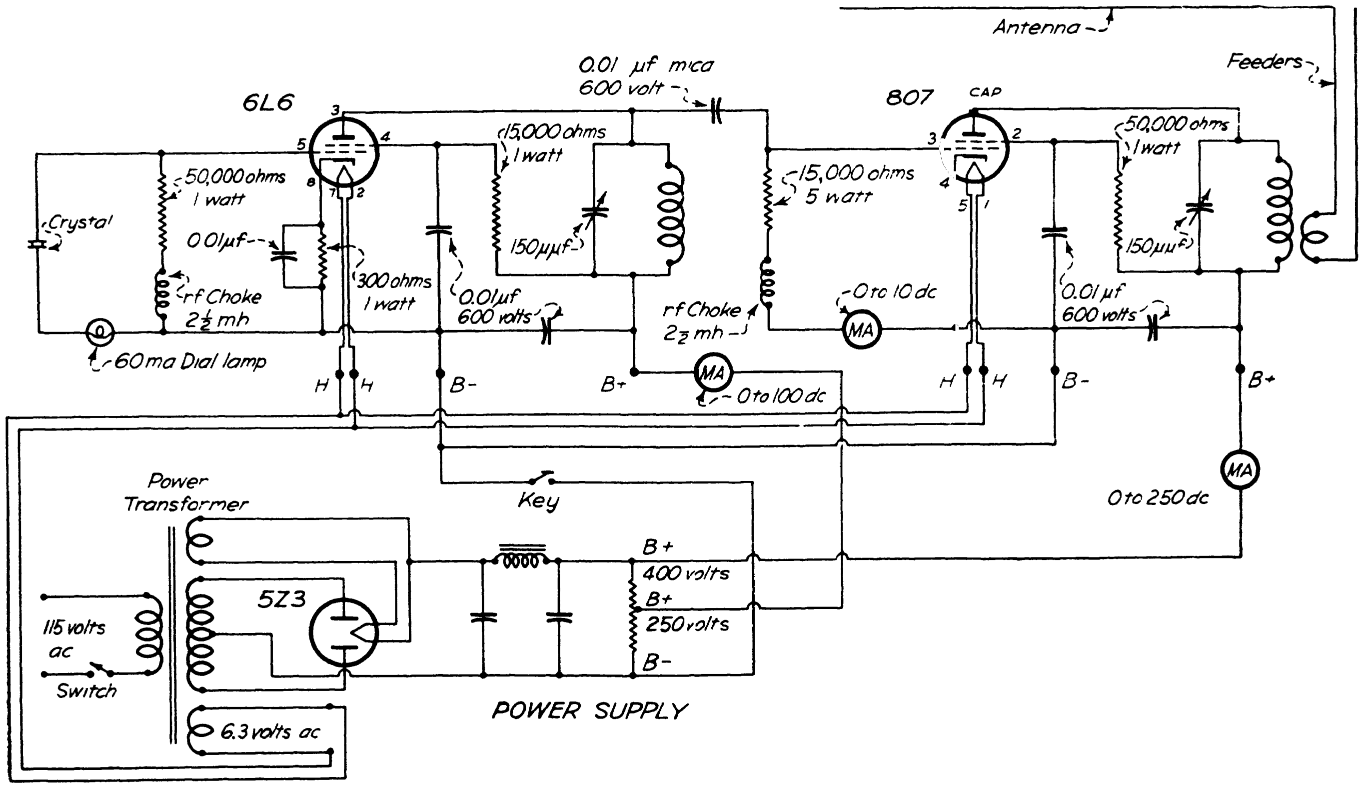


FIG. 460. The schematic circuit for the 6L6-807 transmitter.

that both circuits have no B voltage when the key is up. If the oscillator alone is keyed, the bias on the amplifier is reduced and the amplifier tube overheats.

How to Operate It

Step 1. Hold down the key. Tune the oscillator for dip.

Step 2. Tune the amplifier for meter dip. The grid excitation for the 807 should not be over 5 milliamperes.

Step 3. Couple the antenna to the amplifier tank coil. The coupling between these coils should be loose. If the coupling is too tight, you are apt to send out two or more signals, one on the frequency of your crystal and the other at some other frequency. Looser coupling concentrates the available power on one frequency.

Step 4. Tune the antenna to the point at which the dial light in the feeder glows most brightly. Following this process, recheck the tuning of the oscillator and the amplifier. This process is more fully explained in Chapter 23, "Antennas."

Loosen the coupling between the antenna if harmonics are reported.

PART 4: OTHER TRANSMITTER-CIRCUIT COMBINATIONS

A more powerful transmitter can be arranged by connecting the 6L6 oscillator to the 807 push-pull amplifier (see Fig. 461). This is an excellent circuit which will only be mentioned here as a possi-

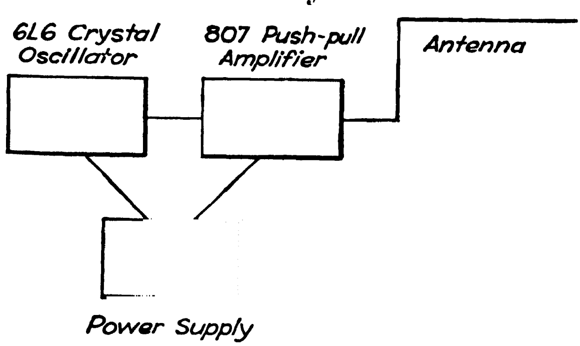


FIG. 461. This block diagram shows another possible arrangement of the transmitter units you have studied. The details of this circuit are omitted because higher voltages are required than are provided for in this text.

bility with the equipment you have studied. For best efficiency, this circuit operates on higher voltages than are practical for a beginner to use, and so no detailed description will be given here.

Note that link coupling is needed between the plate tank coil of the oscillator and the grid coil of the 807 amplifier (see Fig. 461). Another circuit combination which can be used when you wish to

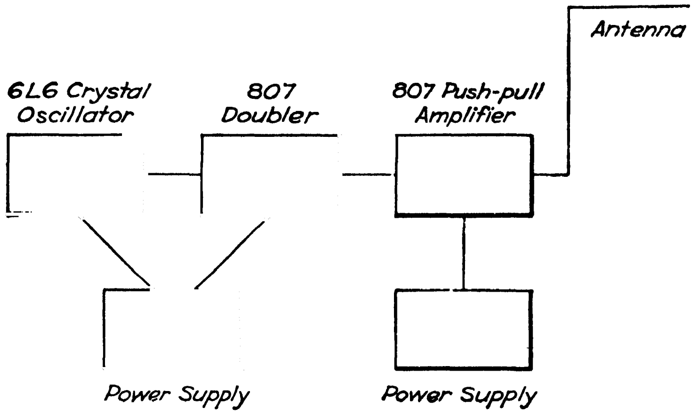


FIG. 462. This is another possible arrangement of the transmitter units for higher frequency operation.

operate on the higher frequencies is the 6L6 oscillator, the 807 doubler, and the 807 push-pull final amplifier (see Fig. 462).

PART 5: THE ANTENNA COUPLING

While the end-fed single-wire antenna described in connection with the crystal oscillator is simple and easy to get into operation,

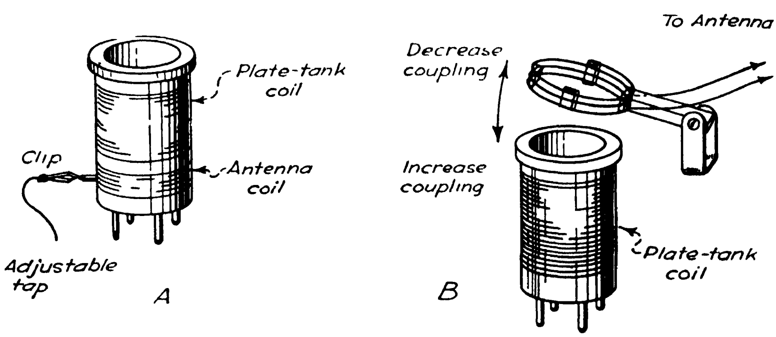


FIG. 463. Here are two ways to couple to antenna and to the transmitter.

it lacks the efficiency of other types of antennas. The part of the antenna which is used for the feeder is brought into the operating room. Radio waves radiated from this part of the antenna lose power to the nearby building.

A better type of antenna is the zeppelin, which has a two-wire feeder. Since little or no energy is radiated from the feeders, they may be brought into the operating room without the loss of radiated power that occurs when the single-wire end-fed antenna is used. This antenna is described in Chapter 23, "Antennas."

The antenna may be coupled to the transmitter by a coil of four turns, as shown in Fig. 463. This coil may be wound on the ground, or B-minus, end of the plate coil form, or it may be wound as shown at *B* and arranged for variable coupling to the plate tank coil.

The method of operating the coupling unit and of tuning the antenna feeders is explained in Chapter 23, "Antennas."

PART 6: REVISITING A BROADCASTING STATION

Now that you have studied and have operated both oscillators and amplifiers and have also learned something about the problems of putting a transmitter on the air, you will enjoy again visiting a broadcast-transmitter station as you did, in spirit at least, in Chapter 1. Now when you visit the room housing the motor generators and transformers which supply the station with the different voltages, some for filament heating and other high voltages for different plate circuits, you can discuss the equipment with the engineer who guides you on your visit.

While you may be lost in the maze of wiring when he shows you the station-circuit blueprint, you will recognize the different parts of the transmitter. You will also recognize the crystal oscillator and the crystal oven that holds this station on frequency.

You will be surprised at the huge transmitter tubes, but you will soon realize that they are nearly all filament-type triodes.

When you revisit the broadcasting studio, you will enjoy checking on the types of microphones and other equipment. You can now visit intelligently. The types of acoustic treatment in the studio, the control-room faders, the panels of beautifully designed and built amplifiers, these things now make sense to you, and when you bid your hosts farewell, you leave feeling that you have passed a milestone in your progress in radio.

Questions

1. Describe the process of tuning the transmitter.
2. Describe the process of coupling the antenna to the transmitter.

CHAPTER 22

RADIO-TELEPHONE TRANSMITTERS

When you read the first chapter of this book you read about a visit to a commercial radio broadcasting station. There you saw the panels, the power supply, and the control boards of a powerful radio-telephone transmitter used to broadcast music and programs Behind these panels, covered for safety because of the high voltages used, are essentially the same circuits that you will learn about in this chapter. You will study only the basic circuits and omit many of the refinements found in the circuits of the broadcast transmitter, leaving them for more advanced study.

In this chapter you will learn about the following things:

Part 1: The Units of a Radio-telephone Transmitter
Part 2: The Two-tube Radio-telephone Set
Part 3: The Principles of Modulation
Part 4: Other Modulator Circuits
Part 5: A Practical Low-power Radio-telephone Transmitter

PART 1: THE UNITS OF A RADIO-TELEPHONE TRANSMITTER

You have studied all of the units used in the transmitter circuit except the modulator, which is new. What are these units? They are the oscillator and one or more radio-frequency power amplifiers, a microphone, a speech amplifier, and a modulator circuit. You have also studied the parts of the speech circuit, in Chapter 19, "Public-address Units." By properly joining a radio-frequency oscillator, an amplifier, a public-address amplifier, and a modulator, you have the basic essentials of a radio-telephone transmitter. Properly coupled to an antenna, this set will transmit.

Remember that coupling, or connecting, any radio-telegraph or radio-telephone transmitter to an antenna is illegal unless you have the proper Federal operator's and station licenses.

You learned in the first chapter of this book that sound waves travel relatively short distances. They quickly die out. You also learned that radio waves can be sent through space over long distances. By properly arranging the circuits, you can cause the radio waves to carry voice, music, or other sounds.

American Telephone and Telegraph Company

RADIO-TELEPHONE TRANSMITTERS

Occupant of a vehicle equipped with a mobile radio telephone may place and receive calls to and from any regular telephone.

Here is a block diagram showing the basic circuits of a simple two-tube radio-telephone transmitter (see Fig. 464). Note that this circuit consists of an oscillator which sets up radio-frequency oscillations and a microphone, connected to the modulator, which is arranged so that currents set up by sound waves can affect the power delivered to the oscillator from the power supply. This

new circuit which enables you to send your voice over the air, riding on the radio wave, is called a *modulator*.

If you want a more powerful radio-telephone set, you can add amplifiers, as shown in the diagram of Fig. 465. Note in this diagram that you place a buffer amplifier between the oscillator and the modulator tube. This is done to prevent the modulator from affecting the frequency of the oscillator.

Now study in detail some of the circuits mentioned above.

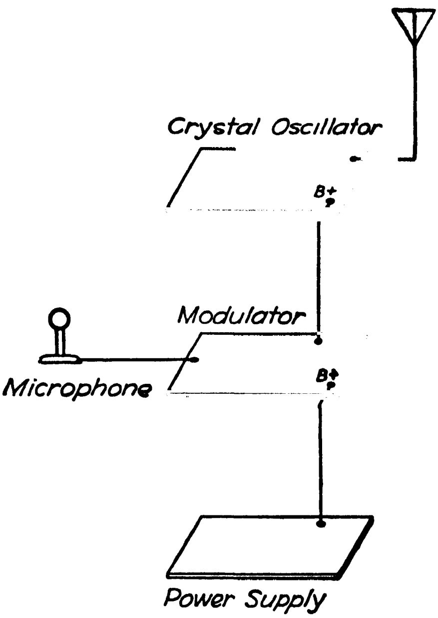


FIG. 464. Connect these circuit units and you have a simple radio-telephone transmitter.

PART 2: THE TWO-TUBE RADIO-TELEPHONE SET

How to Build and Wire the Set

The Oscillator. Use the crystal oscillator that you built in Chapter 19 for this radio-telephone transmitter.

The Modulator Board. Mount the parts for the modulator on a small-sized baseboard, as shown in Fig. 466.

Wire the Modulator Circuit. This is the Heising modulator circuit (see Fig. 467). All the wiring of this circuit handles audio frequency. No special care is necessary in placing the wiring, since little feedback occurs at audio frequencies at such low voltage.

The Microphone Transformer. Use a special microphone-to-grid transformer, or get an audio transformer with a burned-out primary winding. Remove the burned-out winding, and wind a new primary of 15 to 20 turns next to the core. Then slip the secondary over the new primary. Use wood or cardboard end washers to hold the windings in place. Do not use varnish, because later you may want to try changing the number of turns on the primary winding.

Hook up the Batteries. Put a 6C5 tube in each socket (see Fig. 467). Connect the 6.3-volt posts in the power-supply unit to the

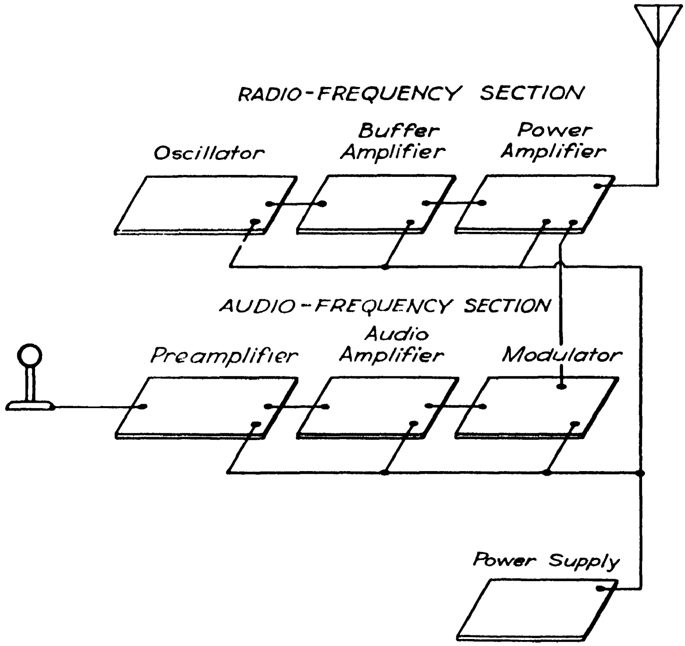


FIG. 465. Here is a good low-powered radio-telephone transmitter.

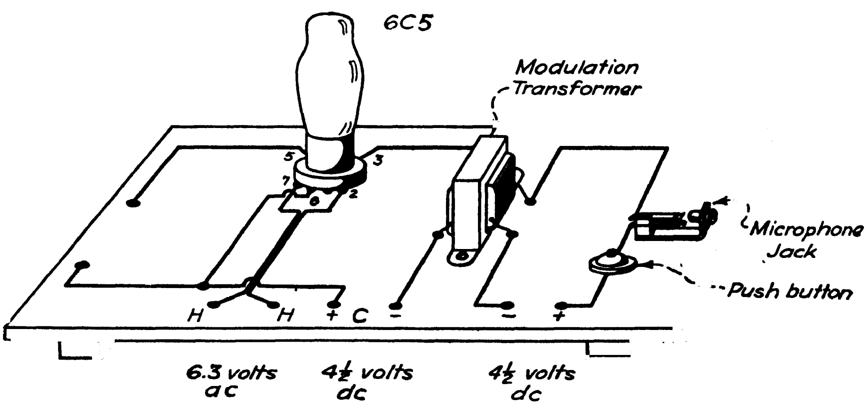


FIG. 466. The layout of parts for the Heising modulator.

heater leads on both the modulator and oscillator boards. Connect 135 volts to the B-positive binding posts on the modulator board. Connect a 4.5-volt C battery to the C binding posts. Connect 4.5 volts direct current to the microphone-battery binding posts.

How to Operate It

Step 1. Turn on the power to heat the oscillator- and modulator-tube heaters.

Step 2. When the heaters are hot, turn on the B power. Couple the dummy antenna to the oscillator coil.

Step 3. Place a broadcast-receiving set in the same room to test the operation of your phone set.

Step 4. Tune the oscillator.

Caution. Use not over 180 volts or the plate of your oscillator to minimize interference with nearby broadcast receivers.

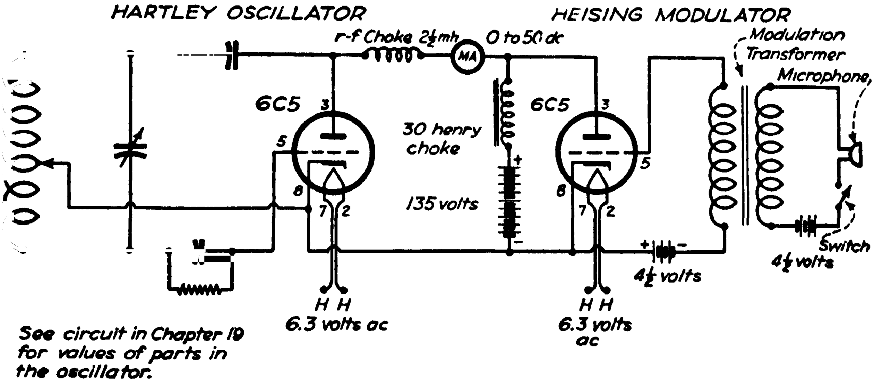


FIG. 467. The circuit diagram of the Heising modulator connected to the Hartley oscillator to make a demonstration radio-telephone transmitter circuit.

Step 5. Tune the broadcast receiver until you hear a thump or hiss. The volume control must be set high. Retune the oscillator if the sound cannot be heard in the broadcast receiver.

Step 6. Hold down the push button in the microphone circuit. Speak into the microphone. This is a "push-to-talk" connection. Hold the microphone at the side of the mouth so that you talk past it.

Test the effect on the quality of the sound the set transmits of speaking loudly, then softly. Test the modulation by speaking in a high-pitched voice, then in a deep voice. Make the same test by whistling.

This microphone and modulator circuit are not highly efficient, and you will find that the voice heard in the broadcast receiver is not like the natural voice, nor is it heard as well as it is over the

telephone. The movement of the plate-meter hand shows the modulation of the set as you speak into the microphone.

Power Control. The power output of the Hartley oscillator can be increased or decreased both by changing the B voltage and by changing the voltage on the grid of the tube (the grid excitation). Adjust the grid excitation on the Hartley oscillator by moving the tap in the tank coil. Move the tap toward the plate end of the coil to increase the power output.

Why It Works

The Oscillator Board. The explanation of how the oscillator board operates was given in Chapter 20.

The purpose of the oscillator in this circuit is to generate a strong, steady radio-frequency oscillating current. This current, properly fed to the antenna, sends out the carrier wave. The frequency of the carrier wave is the frequency to which your receiving set must be tuned in order to pick up the carrier wave.

Purpose of the Microphone. Sound waves that strike the microphone diaphragm cause it to vibrate back and forth, as explained in Chapter 19, "Public-address Units." The vibrations produce pulsating direct currents, called *speech currents*, in the microphone circuit.

These pulsating speech currents correspond to the variations in strength of the sound waves.

Examine the Modulator Circuit. The speech current flows through the primary of the microphone transformer, which produces an alternating voltage in the secondary circuit. This voltage in the secondary circuit makes the modulator-tube grid alternately more and less negative. The C battery keeps a negative bias on the grid to prevent the distortion of the audio-frequency voice current which would occur if the grid became positive enough to draw current from the filament.

How the Modulator Circuit Operates. When the modulator grid is less negative, a swarm of electrons are pulled from the filament to the plate. These electrons rush to the 30-henry choke on their way to the B battery. But the inductance of the choke slows up the rush of electrons toward the B battery and forces the electrons to flow into other parts of the circuit. Some electrons flow to the plate of the oscillator tube. The effect is the same as if the oscil-

lator plate voltage were cut down. This cuts down the flow of electrons through the oscillator tube and weakens the carrier wave generated by this tube.

When the grid of the modulator tube becomes more negative, however, few electrons reach the plate, and the current is weakened. The effect on the 30-henry choke is much the same as if the circuit had been broken. When the current flowing through the choke coil is suddenly stopped, the collapsing field of the coil induces a voltage which tends to keep the current flowing. It now can only get electrons from the plate of the oscillator tube, and so it adds its pull to the pull of the B battery. This has the effect of increasing the B voltage on the plate of the oscillator tube, and now the carrier wave is much stronger.

The inductive effect from the 30-henry choke can double the plate voltage at one instant and at the next reduce it to zero. This is explained later.

This is the process by which sound waves, striking the microphone, strengthen and weaken the high-frequency carrier wave. This increase and decrease of the strength, or amplitude, of the carrier is called *modulation*.

The radio-frequency choke is put into the circuit to confine the radio-frequency surges to the oscillator circuit. No power will be lost now from this circuit, and it will send out a stronger carrier wave.

Questions

1. Does the oscillator in phone sets do the same work that it does in code transmitters?

2. Describe the action of a sound wave as it travels through the air.

3. Show how the choke coil causes electrons from the modulator tube to pile up on the plate circuit of the oscillator tube.

4. When the grid of the modulator tube is negative, show how the choke coil increases the voltage on the plate of the oscillator tube.

5. What is the meaning of the word *modulation?*

6. What is the purpose of the radio-frequency choke next to the oscillator plate?

PART 3: THE PRINCIPLES OF MODULATION

The strong, steady radio-frequency carrier wave set up by the oscillator is shown in Fig. 468. This wave can be made to travel for thousands of miles. The speech currents control, or modulate,

the strength of the carrier wave. When the speech currents are strong, they make the radio-frequency carrier wave strong, and when the speech currents are weak, they weaken it (see Fig. 469).

What is complete modulation? Complete modulation occurs when the strong speech currents double the amplitude of the radio-frequency carrier and the weak speech currents entirely cut off the

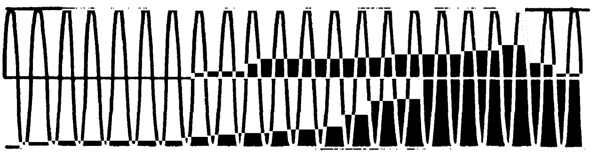


FIG. 468. This is a radio-frequency carrier wave.

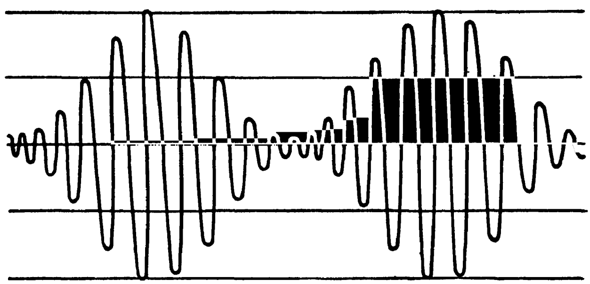


FIG. 469. This carrier wave is 100 per cent modulated.

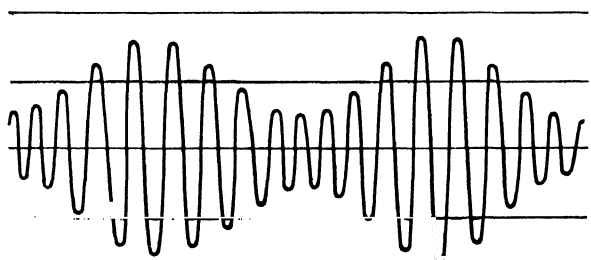


FIG. 470. This carrier wave is undermodulated.

carrier wave (see Fig. 469). This is called *100 per cent modulation.* Such a signal produces the greatest possible effect at the receiver.

What is undermodulation? When the modulation is not complete, that is, when the strong parts of the speech waves do not double the carrier current and when the weak parts do not completely cut off the carrier current, you have *undermodulation* (see Fig. 470). An undermodulated wave may produce a signal of good

tone quality at the receiver, but it will not produce as loud a signal as a 100 per cent modulated wave.

What is overmodulation? When the voice currents are so strong that they more than double the strength of the carrier wave and when the weak parts of the wave shut off the carrier wave for several cycles, you have *overmodulation* (see Fig. 471). An overmodulated wave may produce a louder signal than a 100 per cent modulated signal, but the tone quality will be poorer.

Overmodulation also produces harmonics which distort the music and produce interfering frequencies. It causes broadening of the

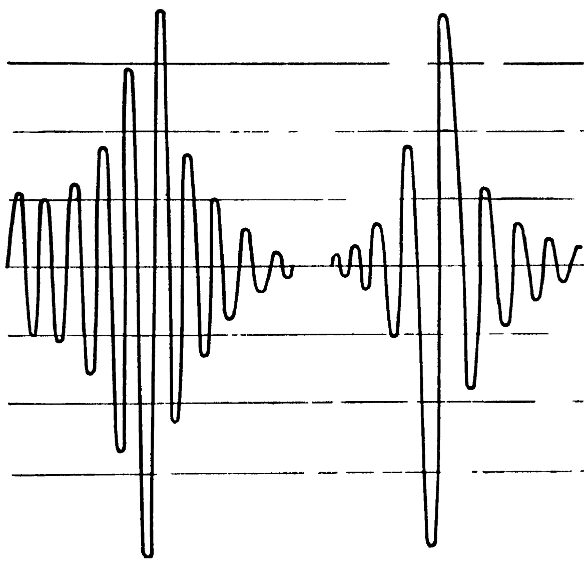


FIG. 471. This carrier wave is overmodulated.

carrier wave and resulting interference with other stations. Hiss heard at the receiver is an indication of overmodulation.

What are side bands? The voice and music frequencies of the sound waves are combined with the carrier wave during modulation to form a wave that covers a narrow band of frequencies equal to the carrier plus the sound frequencies and the carrier minus sound frequencies. These frequencies added to and subtracted from the carrier wave are called *side-band frequencies*. The modulated carrier wave must be broad enough to include the frequencies above and below the carrier if clear, accurate music is to be produced by the receiver. Without side bands at least 5000 cycles wide, the

fidelity of music is poor, because the high frequencies of the music are cut off.

Questions

1. What is meant by 100 per cent modulation?
2. Is the voice distorted in a set which has 100 per cent modulation?
3. Can you broadcast over satisfactory distances with a set which is modulating 100 per cent?
4. What is undermodulation?
5. Can you send as great distances when the set is undermodulating as when it is modulating 100 per cent?
6. Is there distortion in undermodulation?
7. What is overmodulation?
8. Can you send as great distances when the set is overmodulating?
9. Is the voice distorted when it is modulated over 100 per cent?

PART 4: OTHER MODULATOR CIRCUITS

Use a modulation transformer. While the choke is a simple and effective method of modulating an oscillator, more efficient

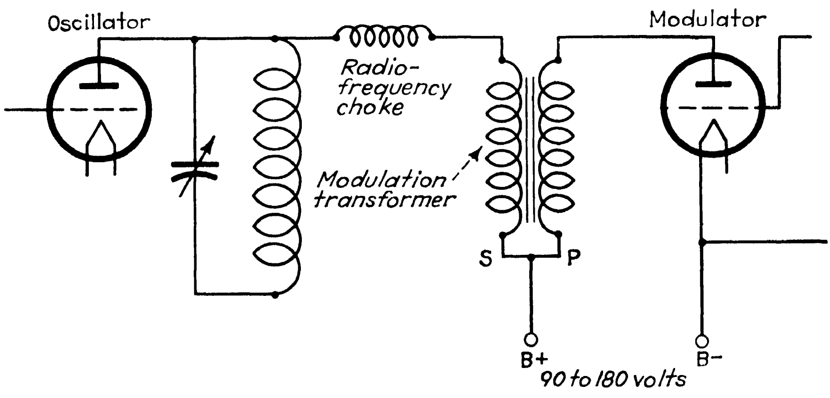


FIG. 472. Plate modulation. This method is used to match tube impedances.

methods can be used. One such method uses a modulation transformer in place of the cheaper choke coil.

When to Use This Circuit. A modulation transformer is used in this circuit to match the plate impedance of the tubes used (see Fig. 472). The alternating-current resistance of the primary is selected to be the same as the plate resistance of the modulator tube. The alternating-current resistance of the secondary must be the same as the oscillator plate resistance.

This transformer is more expensive than a choke but produces better modulation.

How to Change the Circuit Wiring. Connect a 3:1 modulation transformer in place of the 30-henry choke on the modulator board (see Fig. 472). Other transformer ratios depend on tubes used. Connect one end of the primary to the modulator plate. Connect the other ends of the windings together.

Why It Works. If neither the choke nor the transformer were in this circuit, the B battery would exert the same pull upon the electrons on both the oscillator and the modulator plates. But the purpose of the modulator tube is to control the pull upon the electrons on the oscillator plate, modulating or controlling their flow to fit the variations of the voice current. The circuit must be arranged so that the changes in modulator pull can force the plate current to change. This can be done if the modulator voltage gains control in some way over the plate voltage.

When the 30-henry choke was used, its inductive effect, caused by the modulator plate voltage, gave it the desired control over the oscillator plate voltage.

In this circuit the step-up ratio of the modulation transformer gives the voltage on the modulator plate the control of the oscillator plate voltage needed to produce excellent modulation.

When the modulator grid is positive, a large number of electrons is pulled to the plate. On their way to the B battery, the electrons rush through the transformer primary. These electrons flowing through the primary induce a voltage in the secondary but in the opposite direction, toward the oscillator plate.

The secondary voltage is three times stronger than the voltage in the primary. But now the secondary drives electrons toward the oscillator plate, opposing the pull of the B battery. At this instant the B-battery pull is weakened by the interference from the modulator voltage that operates through the 3:1 transformer. The weaker plate voltage reduces the strength of the carrier wave.

When the grid of the modulator tube is negative, the flow of electrons through the tube is cut down and the plate current is weaker. Less voltage is induced in the secondary, and so the carrier wave is stronger.

A sudden drop in the current flowing in the transformer primary will induce a voltage in the secondary that is in the opposite direction to the voltage when the grid was positive. The secondary now tries to pull electrons off the plate of the oscillator. This

makes the plate current stronger, which will increase the amplitude of the carrier at this instant.

The radio-frequency choke keeps the radio-frequency surges in the oscillator circuit out of the modulator circuit. Radio-frequency surges in the modulator circuit cause tubes and other apparatus to burn out, besides causing distortion in the speech currents.

Questions

1. Explain the action of the modulation transformer.
2. What is the direction of the voltage in the secondary of the modulation transformer when the current through the primary coil is flowing down?
3. Compare the action of the modulation transformer with that of the choke coil.

When is grid modulation used? Grid modulation is used in the final amplifier stages (see Fig. 473). It is an inexpensive method of modulation used on high-power sets. Grid modulation is less efficient than is plate modulation.

New Coupling Method. By connecting the output of the modulator plate circuit to the grid circuit of the amplifier through a transformer, you can control the excitation of the last stage by controlling the flow of electrons on the grid of the tube.

Plate modulation is more popular for small tubes, while grid modulation is used almost exclusively for large tubes and in the higher powered sets.

The Modulator and the Oscillator. This is the same modulator hookup (Heising) that was used in earlier experiments. The final amplifier stage is the same as the one described in Chapter 20, "Power Oscillators and Amplifier Circuits." The method of coupling the modulator to the final stage is new.

How to Wire the Set. Connect the primary of an audio transformer in the plate circuit of the modulator tube. Connect the secondary in the grid circuit of the final amplifier tube. The secondary winding must be able to carry the grid current of the amplifier stage. Shunt the secondary by a 0.00025-microfarad radio-frequency by-pass condenser. If the primary has too high resistance, it will change the grid bias (see Fig. 473).

Several stages of amplification may be added to increase the amplitude of the modulated carrier current before coupling the output of the last stage to the antenna. The C bias is furnished

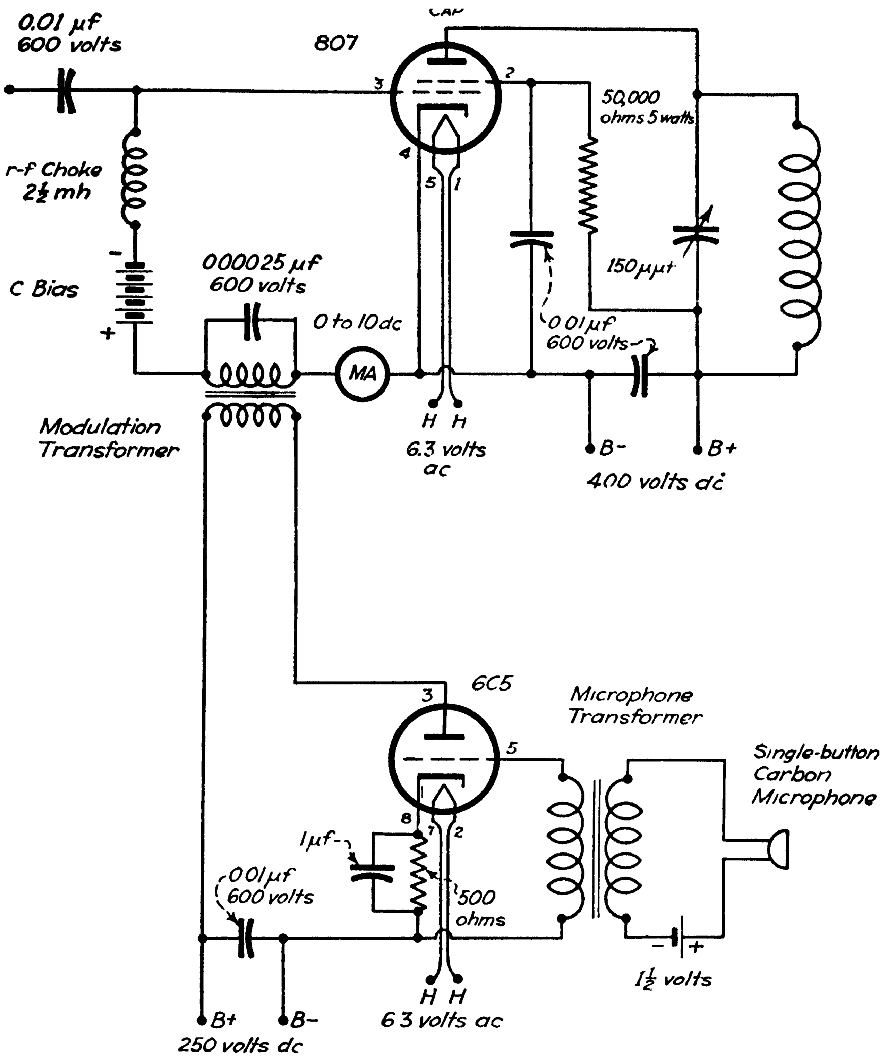


FIG. 473. Grid modulation of a final power amplifier.

by a C battery or by a small power supply. A bias resistor cannot be used here.

Why It Works. When many electrons flow in the modulator circuit, a strong current flows through the coupling-transformer primary. This current induces a voltage in the opposite direction through the secondary of the transformer.

The secondary voltage draws electrons from the amplifier-tube

grid and makes it more positive. When the less negative grid attracts electrons from the filament, it adds to the flow of current through the amplifier tube and strengthens the plate current at this instant. More carrier current now flows in the antenna.

When the modulator current is weak, few electrons flow, the current through the transformer primary is weakened, and the current induced in the transformer secondary flows in the opposite direction. This forces more electrons on the oscillator grid, and it becomes more negative. The negative grid cuts down the flow of electrons through the amplifier tube, and the plate current is weakened. This weakens the carrier current in the antenna.

Now trace the modulation process through this hookup. A strong voltage is applied to the circuit from the amplifiers at the left. The amplitude, or strength, of the input voltage is steady. But when you talk into the microphone, this changes the modulator plate current, which interferes with the electron flow in the grid circuit of the amplifier. This modulates, or changes, the strength or amplitude of the plate current, to fit the amplitude and wave form of the voice wave. Likewise, the plate current charges cause similar changes in the antenna current and in the radiated carrier wave.

Questions

1. Does the grid become more or less negative when a strong current flows through the primary of the audio transformer?

2. When the current increases in strength in the primary of the audio transformer, does this increase or decrease the strength of the carrier wave which is broadcast?

PART 5: A PRACTICAL LOW-POWER RADIO-TELEPHONE TRANSMITTER

You have covered enough of the basic principles of modulation methods to be able to put together a practical radiophone transmitter that will deliver from 15 to 20 watts of power to the antenna.

This set is made up of an oscillator and a power amplifier that you have already studied in connection with the radio-frequency power source. It also includes one of the public-address amplifiers which you studied in an earlier chapter.

These units are made into a radiophone set by the addition of a modulation transformer attached as explained here. This is an excellent set for amateur use.

Caution. While in operation this set must be under the control of a person who holds the amateur operator's license, and the station must hold a license issued by the Federal Communications Commission. Severe penalties are imposed for violations of the Federal laws governing amateur operators.

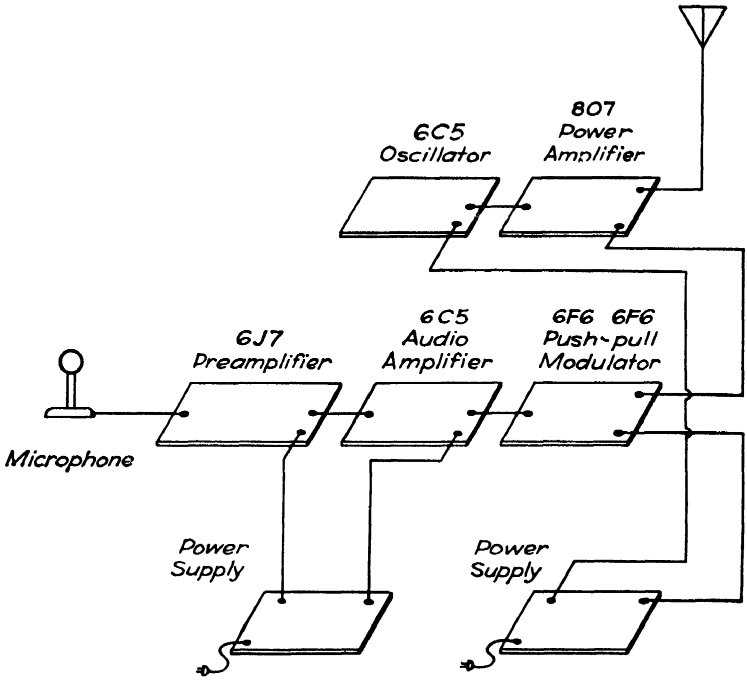


FIG. 474. This is a practical low-powered radio-telephone transmitter made by connecting parts you have used in studying transmitters.

How to Build and Wire the Set

The Circuit. The block diagram, Fig. 474, shows the different circuit units and how they are joined. Also examine the schematic circuit, Fig. 475. Note that separate power supplies are used for the public-address amplifier and for the transmitter.

Minor changes must be made in the tuning circuits of the crystal oscillator and of the radio-frequency power amplifier to make them usable for operation on amateur frequencies. The only change in the public-address amplifier is the substitution of a new output transformer.

The Crystal Oscillator. Use the crystal oscillator described in Chapter 20, "Power Oscillators and Amplifier Circuits."

The Power Amplifier. Note that the transmitting type of power tube, the 807, is shown here. It provides good power output. This is a better tube than the receiving type of tube.

The Coil and Condenser. Use the same size of coil and condenser on the power-amplifier board that you use on the crystal oscillator. Wind a three-turn coil on the plate end of this coil to use for coupling to the antenna.

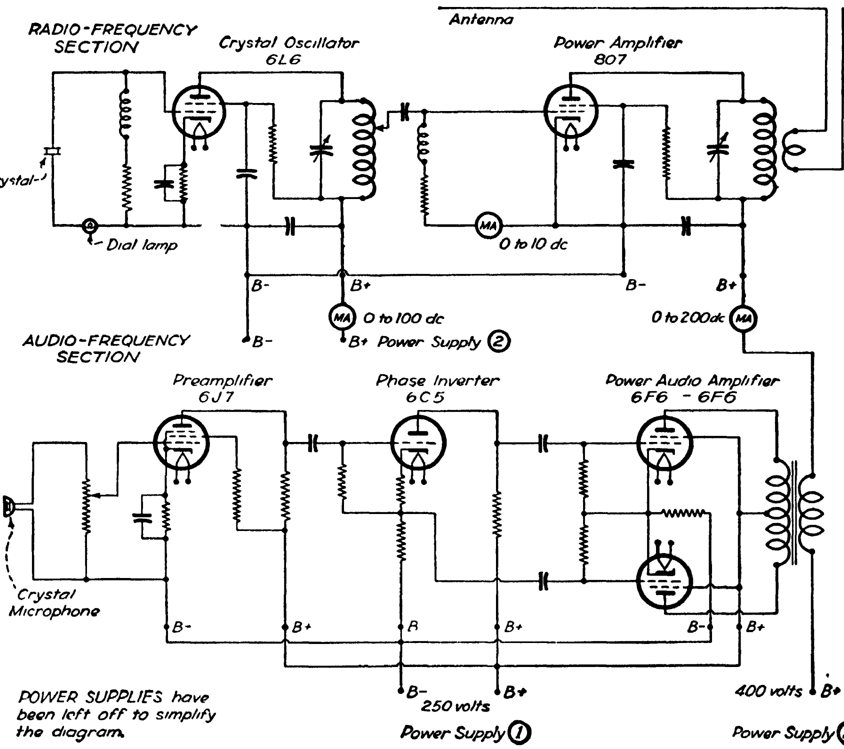


Fig. 475. The schematic diagram of the low-power radio-telephone transmitter. The two power supplies have been omitted for simplicity.

Changes in the Public-address Set. The only change in this set is to replace the output transformer with a modulation transformer. Select this transformer to fit the output tubes in the public-address amplifier and the final power amplifier in the radio-frequency part of the set.

Power-supply Requirements. Use a power supply for the public-address unit which will deliver 250 volts at 150 milliamperes.

The transmitter portion will need a separate power supply with 250 volts for the crystal oscillator and 400 volts for the 807 final

power amplifier. The crystal oscillator will draw about 20 milliamperes when loaded, and the 807 will draw about 90 milliamperes at 400 volts on the plate and 225 volts on the screen. Use the 5Z3 type rectifier tube in the transmitter power supply.

How to Hook Up the Set

Step 1. Hook up the crystal oscillator to the 807 power amplifier.

Step 2. Attach the transmitter power supply. First test the filament wiring. Then shut off the power supply, and attach the B-positive wires. Attach the B-positive wire from the crystal oscillator to the 250-volt tap on the power supply. Attach the screen of the 807 tube to the 250-volt tap. Attach the plate of the 807 to the 400-volt tap. Note that the B-plus wire from the 807 runs to the output of one end of the modulation transformer. The other end runs to the 400-volt B-plus tap on the transmitter power supply.

Step 3. Attach the antenna to the coupling coil on the final-amplifier tank coil.

Step 4. Hook the units of the public-address amplifier together.

Step 5. Plug in the microphone, and the set is ready to operate.

How to Operate the Set

Caution. This set may be operated on the air only by a licensed amateur operator. Operation by any other person, except as specifically directed in the Federal regulations, is illegal.

Step 1. Turn on the transmitter power supply. Adjust the oscillator and amplifier so that both are in oscillation. Watch the plate meters for excessive current.

Step 2. Tune the crystal oscillator and the amplifier to the frequency on which they are to operate. Keep well within the frequency band. *Do not* tune near the edge of this band.

Step 3. Turn on the public-address power supply. Turn down the volume control. Advance the volume control, and speak into the microphone.

Questions

1. What changes must be made in the set in order to have it operate on amateur frequencies?

2. In Step 2 of "How to Operate the Set" the statement was made: "*Do not* tune near the edge of the band." Why was this statement made?

CHAPTER 23

ANTENNAS

The antenna has two important jobs to perform in radio transmitting and receiving circuits. The transmitting antenna absorbs energy from the oscillating circuit of the transmitter. It then transforms this energy into the effect that we have called the *radio wave*, which travels through space from the transmitter. Energy from the passing radio waves sets up weak radio-frequency currents in the wire of the receiving antenna. These currents flow through the lead-in wire to the receiving set and produce sound.

Types of antennas. Many different kinds of antennas have been designed and used, both for receiving and for transmitting. You will study in this chapter only those types of antennas which are now in general use. You will avoid special types. Essentially, all these antennas are either of the type discovered and used by Hertz in his experiments during the 1870's, or a modification known as the *Marconi antenna.* The various constructions of antennas and the methods used in suspending them look different, but in principle they are all the same. The difference often lies in the method by which energy is made to flow between the set and the antenna. In this chapter are described some of the different constructions as well as different methods by which the antenna is fed.

Hertz and Marconi antennas. The Hertz antenna is essentially a straight wire, insulated at each end, with a lead-in, or feeder, wire attached to some definite position along its length. This antenna, in its fundamental form, is made approximately half a wavelength long. Thus a simple half-wave Hertz antenna to be used by a broadcast-transmitting station operating on a frequency of 1000 kilocycles (a wavelength of 300 meters) would be 150 meters long. Since 1 meter is equal to about $3\frac{1}{4}$ feet, this antenna would be approximately 490 feet long. So long an antenna is impractical to build, and so a different arrangement, the Marconi antenna, is usually used.

A Marconi antenna is connected to earth through the set. The ground acts as half the antenna, so that the antenna needs to be only one-quarter wavelength long. Thus a 1000-kilocycle broadcast-transmitter antenna will be only approximately 245 feet long. Most modern stations use the tower itself as a Marconi antenna.

Antennas used by radio amateurs on the higher frequencies are generally of the Hertz half-wave type. This antenna can be used because at these higher frequencies, a half-wave antenna is much shorter than a broadcast-frequency antenna.

Operation on harmonics. The Marconi antenna and the end-fed Hertz or zeppelin antenna operate well on several frequencies. Thus one antenna, built for a low frequency, is often used. Such an antenna may be operated on higher frequencies which are harmonics of the low frequencies.

For the advanced experimenter, the efficiency gained by using separate antennas often more than offsets the inconvenience of building them and making the necessary switching arrangements.

In this chapter you will learn about the following things:

Part 1: General Construction Information for Your Antenna
Part 2: The Fundamental Operating Theory of Half-wave Antennas
Part 3: The Hertz Center-fed Antenna
Part 4: The Doublet Antenna
Part 5: The End-fed Zeppelin Half-wave Antenna
Part 6: The Simplest Antenna—The End-fed Hertz
Part 7: The Marconi Antenna
Part 8: The Coaxial Cable

PART 1: GENERAL CONSTRUCTION INFORMATION FOR YOUR ANTENNA

Receiving antennas. Make your receiving antennas of No. 14 enameled copper wire. Hard-drawn copper wire is better for long antennas than ordinary soft-drawn wire, which will stretch enough in heavy wind or under ice loads to change the tuning of the antenna and affect its operation. Bare copper wire, when new, is efficient, but it will corrode rapidly when exposed to the air. Enameled wire resists corrosion, and it will remain in good condition for an indefinite length of time.

Receiving antennas need insulators at the ends of the wire and wherever the leadin is fastened to a support. Use an insulator between the wire and the rope at the ends of the antenna. In general, the insulator should provide a long leakage path between

the wire and the support. A short corrugated insulator has as long a leakage path as a longer insulator that has no corrugations. Glazed insulators are best. Glass insulators are satisfactory for receiving antennas.

Frequency and wavelength. When you tune your home radio, you select a station by setting the dial to the frequency assigned it by the Federal Communications Commission. The Federal Communications Commission assigns the station frequencies instead of assigning the wavelengths on which they are to operate. It is easier to measure frequency than wavelength. You will remember from Chapter 1 that frequency and wavelength are two different ways of expressing the same thing. The frequency marking is easier to read and to understand.

Convert wavelengths into frequency by this formula

$$\text{Wavelength in meters} = \frac{300{,}000}{\text{frequency in kilocycles}} = \frac{300{,}000}{f}$$

You can also find the frequency from the wavelength by using this formula:

$$\text{Frequency} = \frac{300{,}000}{\text{wavelength in meters}} = \frac{300{,}000}{\lambda}$$

The letter f means frequency, and the Greek letter λ (lambda) means wavelength.

Transmitting antennas. The same antenna can be used for both receiving and transmitting by means of a double-pole double-throw (dpdt) switch. Antennas for low-power transmitters can also be made of No. 14 enameled copper wire. Long antennas and those which have heavy insulation at the center should be made of No. 10 or 12 wire. Insulation should be much better than for receiving antennas, since much higher voltages are used. You can obtain special strain insulators for transmitting antennas.

Height of antenna. The antenna should be as high as possible above ground for best efficiency. Higher antennas are better radiators and receptors than lower antennas. The minimum desirable height is one-quarter wave.

Position of the antennas. The antennas should be placed as nearly as possible at right angles to power lines or to wiring in the building near which it is erected. This prevents a transmitter

antenna from inducing unwanted radio-frequency currents in the power lines and also prevents a receiving antenna from picking up hum from the power lines. The position in which the antenna is built has some effect on the direction in which it will receive and transmit most efficiently.

Questions

1. Which type of antenna will operate satisfactorily on only one frequency?
2. What types of insulators should be used?
3. What is the minimum distance above the ground that an antenna should be placed?
4. Describe the best position of the antenna with respect to nearby power lines.

PART 2: THE FUNDAMENTAL OPERATING THEORY OF HALF-WAVE ANTENNAS

What is a half-wave antenna? The half-wave, or Hertz, antenna is a basic type of antenna. Most of the common high-

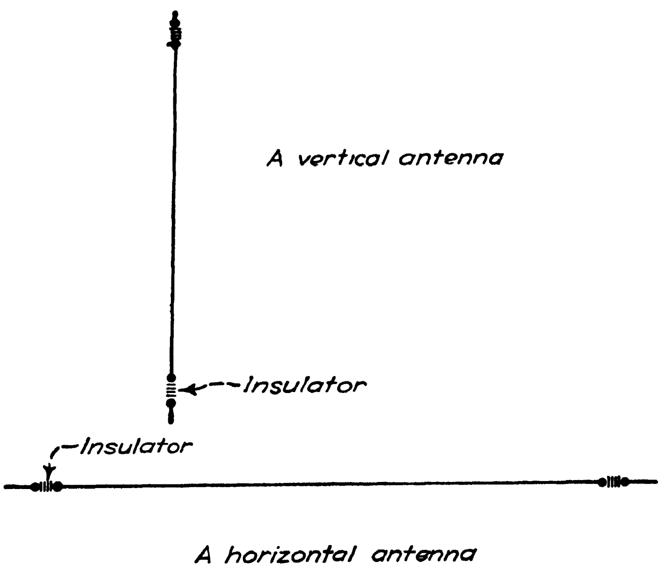


FIG. 476. The half-wave Hertz antenna may be placed either in a vertical or in a horizontal position. The operating principles are the same in either case.

frequency antennas are of this type. When you understand how it operates, you can easily see how the other common kind of antenna, the Marconi, works. The half-wave antenna gets its name from the fact that it is half a wavelength long. It may be either a horizontal or a vertical length of wire, as shown in Fig. 476.

There are several types of feeders. The set can be connected to a half-wave antenna in many different ways. The wire or wires used for this purpose are called *feeders*, or *transmission lines*. The several types of feeders that you will study are described later in this chapter. In each of them a different type of feeder or transmission line connects the set to the antenna. When the feeder is properly constructed, its only purpose is to carry the radio energy between the antenna and the set. Since the feeder does not act as an antenna, you can study the antenna by assuming that the set is located at the antenna.

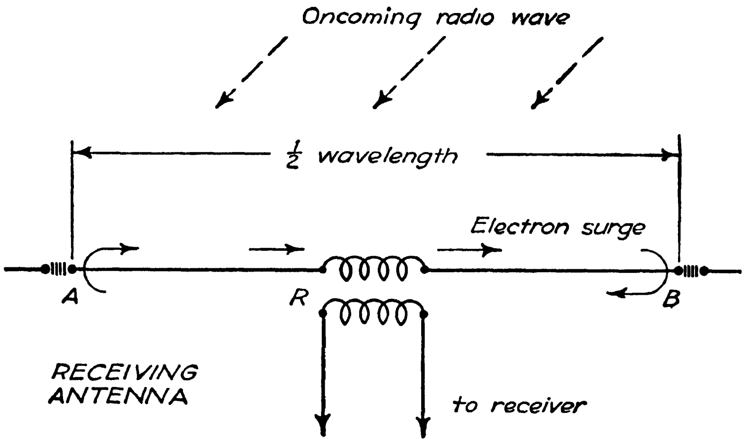


FIG. 477. How electron surges travel through a half-wave receiving antenna.

Electron surges in a receiving antenna. Figure 477 shows a half-wave antenna with a receiver connected to it. The coil in the antenna is supposed to be so small that it does not affect the operation of the antenna.

When a radio wave strikes the antenna wire, it starts a surge of electrons which flow from *A*, through the wire, to the other end at *B*. The electron surge then reflects, or rebounds, from the *B* end and surges back to the other end of the antenna at *A*. When the electron surge arrives at *A*, it again rebounds and surges back through the antenna. At the instant of rebound, the next radio wave arrives and starts another surge which gives the first surge a boost.

Some of the power of the first electron surge is lost in forcing its way through the resistance of the antenna wire. Some of it is

absorbed by the set. This second surge replaces the energy lost by the first surge and builds the first surge up to its former strength. A steady surging, or oscillation, of electrons through the antenna will continue as long as the incoming radio waves supply energy.

How electrons are distributed in each surge. The arrows used in this discussion show the directions in which an electron surge travels through the wire. In Chapter 3 an electron surge was described as a progressive setting in motion of free electrons along the wire.

In the antenna the radio-frequency surges occur very rapidly, many thousands of times a second, depending on the frequency

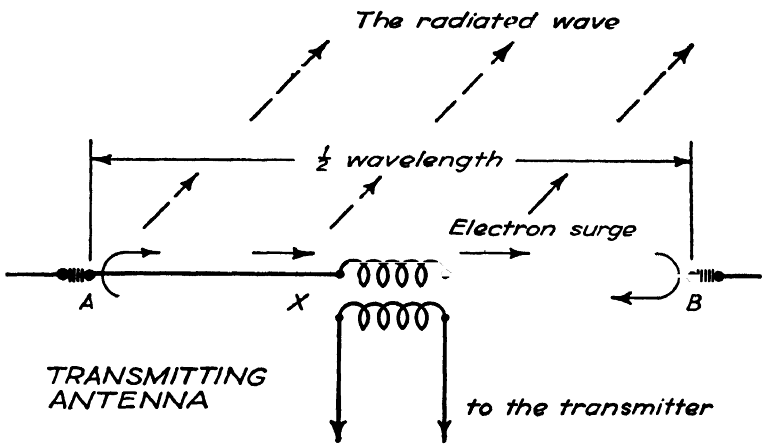


FIG. 478. How electron surges travel through the half-wave transmitting antenna.

for which the half-wave antenna is tuned. If the frequency is the 680,000 cycles per second that we talked about in Chapter 1, the surges change direction 680,000 times in each second.

At the ends of the antenna, where the electrons in the surge can go no farther, they crowd together, and the voltage here is high. This is another way of saying that at the ends of the antenna the voltage is greatest and that no current is flowing there. In the center of the antenna, where the receiver is connected, there is much current and little or no voltage.

The receiving antenna and the transmitting antenna operate in the same way. Now suppose we replace the receiving set at *R* with a power oscillator *X* (see Fig. 478). The oscillator acts as an electron-surge pump. When coupled to the antenna, as

explained in Chapter 20, this electron pump will set up powerful electron surges through the antenna.

Let us follow a surge through the antenna wire. Electrons surge from *X* to the end of the antenna at *A*. At once, a tremendous crowding of electrons occurs at *A*; then their energy forces electrons back through the wire to *X*. This corresponds to a half cycle of the transmitted wave.

Electrons are now forced to the other end of the antenna at *B* by the oscillator; they rebound and surge back to *X* again, thus completing the full cycle, or oscillation.

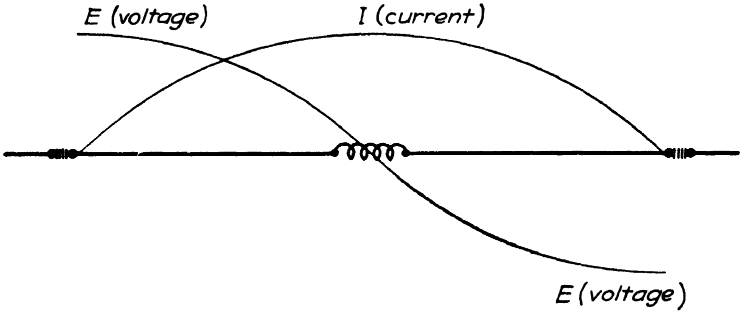


FIG. 479. This voltage-current graph shows by means of lines how a radio engineer would draw the effect of surges in a half-wave antenna. The distance of the curve from the antenna shows the strength of the quantity shown by the curve. Here voltage is high at the ends and current is high at the center of the half-wave antenna.

The engineering graph in Fig. 479 shows by means of curved lines the relative strengths of both current and voltage along the antenna. This is another use of the wave-form pictures you studied in an earlier chapter. The energy in these powerful surges in the antenna sets up radio waves which travel away through space. The energy radiated from the antenna is replaced by the surges following.

What happens when an antenna is too long? Now watch the action of electrons in an antenna that is longer than half a wavelength for the frequency being transmitted (see Fig. 480). The oscillator starts electrons through the antenna from *X*. The surge reaches *A* and builds up a pressure. Then it reverses and surges back toward *X* again. But the surge reaches *X* too late to get the full help of the oscillator, which has just forced a surge toward the other end at *B*. The surge will go to *B* and start back toward *X*.

Just as it reflects back from B (Fig. 481) the second surge collides with the first surge. The second surge is stronger than the first surge, which has traveled twice the length of the antenna and has lost some of its energy. Both the first and second surges lose energy in trying to oppose each other, with the result that the total current left is quite weak. The strength of the radiated wave will be much weaker than when the antenna had the correct length.

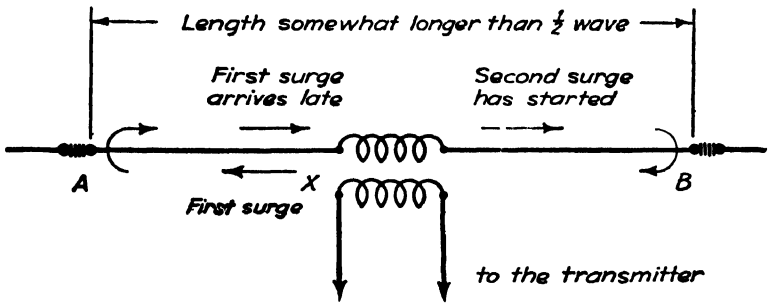


FIG. 480. This antenna is cut too long for the frequency at which it is to operate. The first surge takes too long to travel to A, rebound, and return to X. The second surge has already started so that it receives little help from the first surge.

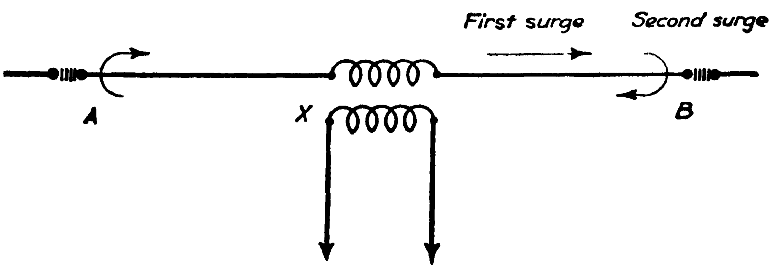


FIG. 481. As the second surge rebounds from B it collides with the first surge. The result is a reduced total current flow in the antenna.

Thus you see why a half-wave antenna works best at the frequency for which it was constructed.

What happens when the antenna length is doubled? Now follow the electron surges through a longer antenna (shown in Fig. 482). Suppose that you increase the antenna to double its original length, or a full wavelength. The surge starts from X toward the end of the antenna marked A. At the same time, a surge is pulled from the end B toward the center of the antenna at X.

The surge toward A reaches the end of the antenna and sets up

a crowding of free electrons, as in the half-wave antenna. This produces maximum voltage at the ends of the antenna.

Examine the graphs in Fig. 483, and you can see how the surges rebounding from the ends of the antenna meet surges from the center of the antenna at the one-quarter wavelength points and produce points of maximum current and zero voltage.

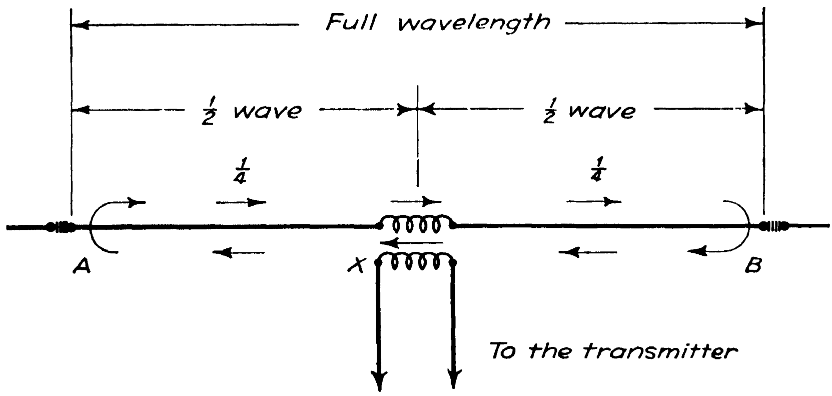


FIG. 482. A full-wave antenna is formed by adding a quarter wavelength of wire to each end of the half-wave antenna.

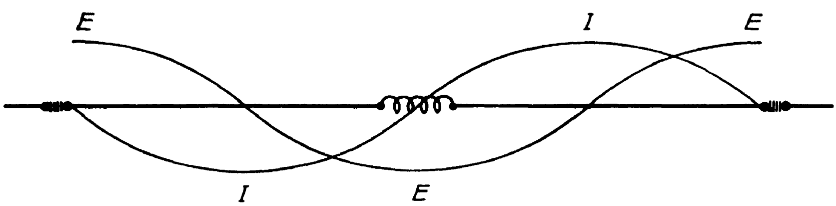


FIG. 483. The voltage-current graph for the full-wave antenna shows that the highest voltage occurs at the ends and at the center of this antenna. Current now is greatest at the quarter-wave points and is zero at the ends and at the center of the antenna.

PART 3: THE HERTZ CENTER-FED ANTENNA

The center-fed antenna is a basic half-wave Hertz broken in the center by an insulator and connected to your transmitter by a pair of feeders (see Fig. 484).

Since it is inconvenient and inefficient to place your transmitting and receiving equipment up in the air at the center of your antenna, some sort of feeder is used to run between the equipment in your operating room and the antenna. This allows the radiating part

of the antenna to be well above the building in which your equipment is located. Thus radio waves are radiated from the antenna more efficiently, and less energy is absorbed by the building.

How to build the feeders. Place a strain insulator at the center of the antenna. You may also use two glass insulators arranged so that the ends of the antenna wires are 6 inches apart.

Make the feeders of No. 14 enameled wire. Cut each feeder to one-quarter wavelength or to any odd quarter wavelength. For example, this may be 67 feet for an 80-meter antenna.

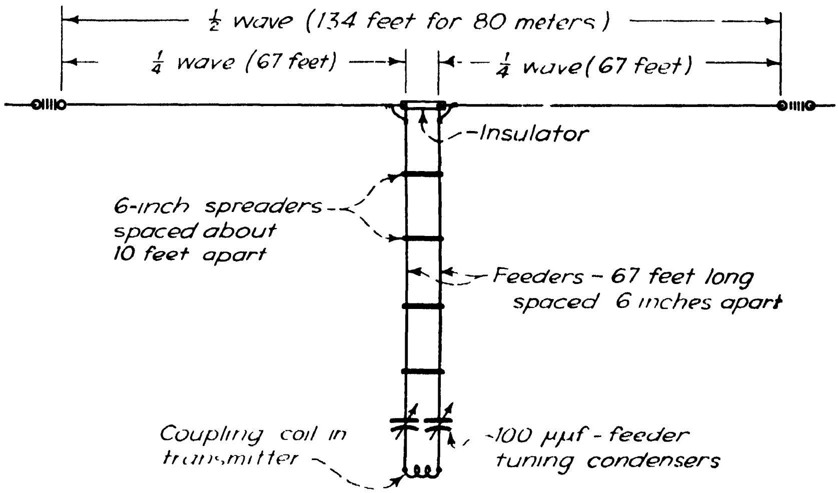


FIG. 484. The center-fed half-wave Hertz antenna. The feeders shown here are separated a distance of 6 inches by spreader insulators. The spreaders are spaced about 10 feet apart along the feeders.

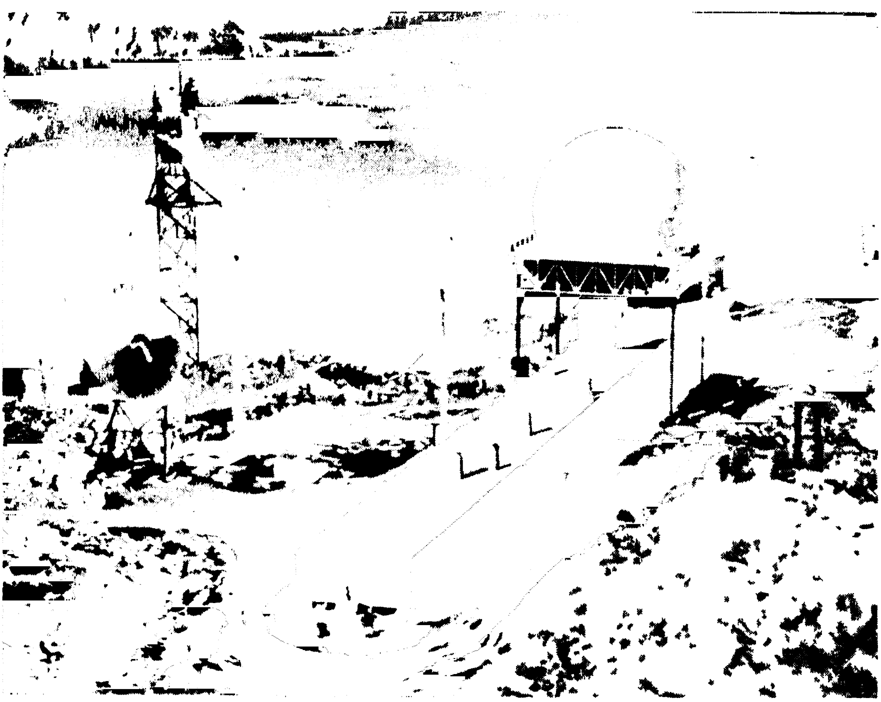
Porcelain or plastic spreaders, spaced about 10 feet apart, are attached to the feeder wires. The feeders are pulled tight enough so that the spacing between wires remains the same at all times.

How to couple the feeders to the transmitting and receiving set. You can use the same antenna for sending and receiving by using the antenna change-over switch to connect the antenna either to the transmitter or to the receiver as you operate your station. Two wires are connected from the antenna change-over switch directly to the antenna and ground posts of the receiver. No other connection is needed.

Some kind of coil is generally arranged to couple the feeders to the tank coil of the final amplifier of the transmitter. This coupler

was described in Chapter 21, "Radio-telegraph Transmitters." Two wires from the other two taps on the change-over switch are attached to the coupling coil.

How to tune the feeders. A 100-micromicrofarad midget variable condenser is connected in each feeder wire to adjust the electrical length of the feeders to the frequency at which the trans-



Bell Laboratories Record

A TYPICAL DEW LINE SITE

Spherical radome houses automatic search radar. Two 60-foot parabolic antennas and two 30-foot dish type antennas maintain communication between DEW early warning stations in our defense line across northern Canada.

mitter is operating. Correct tuning is indicated by the brightness of dial lamps placed in each feeder.

How it works. The operation of the Hertz center-fed antenna is the same as that of the full-wave Hertz antenna described in Part 2 of this chapter.

Mechanically, the center-fed antenna is simply a full-wave antenna with the two central quarter-wave parts formed into the two parallel spaced wires of the feeder.

The coupling coil is still at the center of the antenna. The tuning condensers adjust the electrical length of the antenna to tune it to the frequency of the transmitter.

The electron surges are the same as those described in Part 2.

Only the top half wave of the antenna radiates radio waves into space. The feeders have little or no radiation, because the radiation set up by a surge in one feeder wire is canceled by the radiation from a surge in the other feeder.

PART 4: THE DOUBLET ANTENNA

The doublet is another form of the basic center-fed half-wave Hertz antenna (see Fig. 485). The only difference is in the feeder.

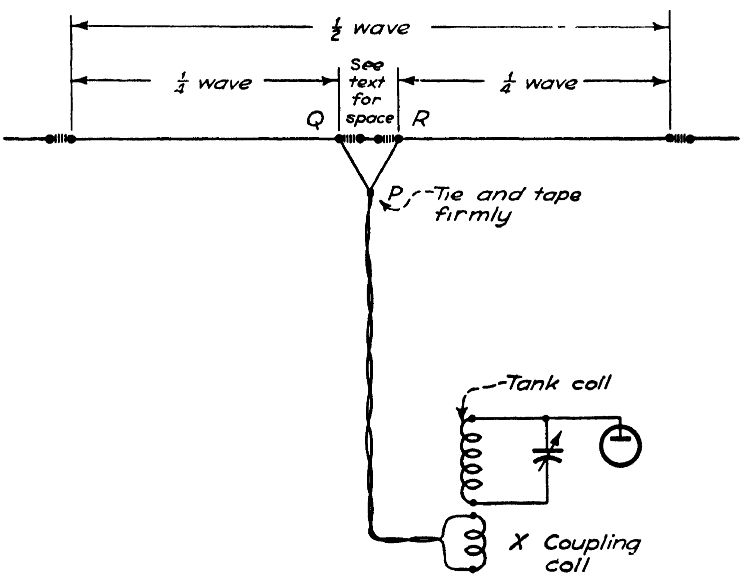


FIG. 485. The doublet antenna is one-half wavelength long.

Instead of using parallel spaced wires, the doublet feeder* is a twisted pair of weatherproofed wires or a special cable. Note the Y connection between the feeders and the center of the antenna.

This antenna is particularly good for receiving, because it picks up less noise than other kinds of antennas. The same antenna may be used for low- and medium-power transmitters.

How to build the antenna. Cut each half of the antenna accurately to a quarter wavelength for the desired frequency (see Fig. 485). Place an insulator at each end of the wire and two insu-

lators at the center. The two insulators at the center should be arranged so that the ends of the antenna wire are spaced 12 inches apart.

How to build the feeder. Use two wires twisted together for the feeder or you may use special weatherproof twisted-pair-feeder wire. The feeders may be any convenient length. No tuning is provided in the feeder wires.

The efficiency of this type of antenna depends on the type of wire used for the feeder. The special feeder wire is more efficient, because it is designed for the purpose.

Spread the ends of the feeder wire, tie and tape them firmly at *P*, and splice them to the antenna at the two center insulators at *Q* and *R* (see Fig. 485). Make the length from the tie at *P* to the attachment of each wire at *Q* and *R* the same as the space from *Q* to *R*.

How to couple the antenna to the transmitter. The ends of the feeder are attached to a pickup coil wound at the ground, or B-minus, end of the tank coil. This coil will have about five turns for a low-powered transmitter such as the crystal oscillator or an oscillator and an amplifier. For lower power, about three turns will do.

You can adjust the loading of the antenna by means of a pickup coil arranged so that it can be moved to vary its coupling with the tank coil.

How it works. The surges through the twisted pair feeders and through the radiating part of the doublet antenna follow the action of the surges in the center-fed Hertz antenna.

The twisted pair feeders radiate no energy because of the opposing fields set up by the surges in the two wires. The surges in each wire are equal and opposite to the surges in the other wire.

Questions

1. Compare the current flow in a doublet antenna to the current in the straight half-wave type.

2. Is the feeder to the doublet an application of the statement that an antenna will oscillate regardless of the point at which it is fed?

PART 5: THE END-FED ZEPPELIN HALF-WAVE ANTENNA

The zeppelin, or zep, antenna is another adaptation of the basic half-wave Hertz. The feeders are connected to the end of the

antenna as shown in Fig. 486. The tuned feeders are the same as those used on the center-fed Hertz antenna.

This antenna is used when the feeders must be at the end of the antenna on account of the location of the operating room and of the available supports for the end of the antenna wire.

How to build the antenna. The antenna proper is half a wave long (see Fig. 486). This is 132 feet for 80 meters. Place insulators at the ends as shown in the diagram.

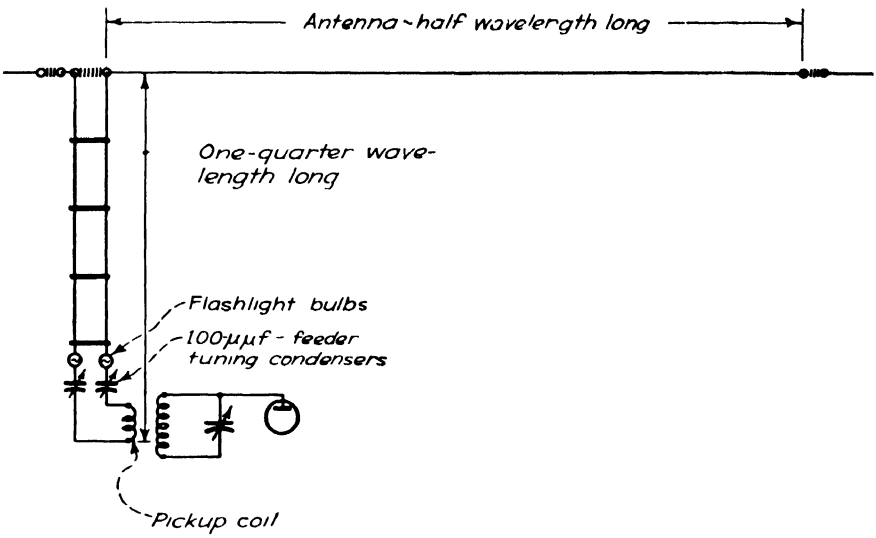


FIG. 486. The zeppelin antenna uses a parallel pair of wires separated by spreader insulators as the feeder. The parallel wires are a transmission line.

How to build the feeders. The feeders are each one-quarter wavelength long (66 feet for 80 meters). They may also be any number of odd quarter wavelengths, such as three quarters, five quarters, etc., if the distance from the operating room to the antenna is greater than 66 feet.

They must be parallel. They are held apart by spreader insulators spaced a few feet apart. The spreader insulators (see Fig. 486) may be purchased or may be homemade. Porcelain or plastic spreaders are excellent. While the spreaders may be from 4 inches to 12 inches in length, 6-inch spreaders are commonly used.

How to operate it. Couple the antenna to the tank coil of your transmitter with an antenna coil of four turns. Tune the feeders by means of two 100 micromicrofarad midget variable condensers

connected, as shown in Fig. 486. Watch the plate milliammeter to see at what setting of the condenser the antenna takes the most power.

A radio-frequency ammeter or a flashlight globe, placed in each feeder wire as shown in Fig. 486, is convenient to show changes of power being supplied to the antenna by different adjustments of the transmitter.

How it works. Now suppose that we change the construction of the full-wave antenna shown in Fig. 482 by folding half of it to form two parallel feeders with the coupling coil at their center

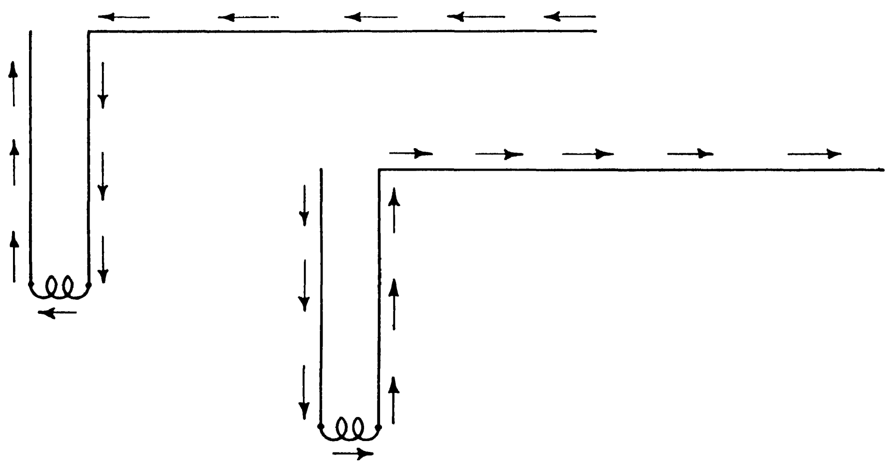


FIG. 487. This shows the electron-surges' travel in the zep half-wave antenna.

point (see Fig. 486). This will leave half a wavelength of the antenna for the radiating part.

The electron surges travel through this antenna as shown in Fig. 487. The oscillator drives a surge of electrons out into one feeder wire and draws a surge of electrons from the other feeder wire. The surges in the two feeders are equal and opposite in direction. Because the feeder wires are placed side by side, radio waves set up by one wire oppose and kill waves from the other wire. For this reason, the feeders radiate little or no energy as radio waves.

The condensers shown in Fig. 486 adjust the timing of the surges in the feeders so that they are exactly 180 degrees out of phase. This leaves the "flat-top" part of the antenna to radiate waves without interference from the feeder wires. But the electron

surges in the feeder wire set up surges in the half-wave part of the antenna proper. These surges, which were explained in Part 2 of this chapter, provide the energy which actually is radiated as radio waves.

Look again at the curve of Fig. 483. Here you note that the coupling coil is at a point of high current and zero voltage. The two ends of the feeder are at high-voltage points and must be well insulated. This end-fed antenna is said to be *voltage fed* because the end of the feeder attached to the antenna is a point of high voltage.

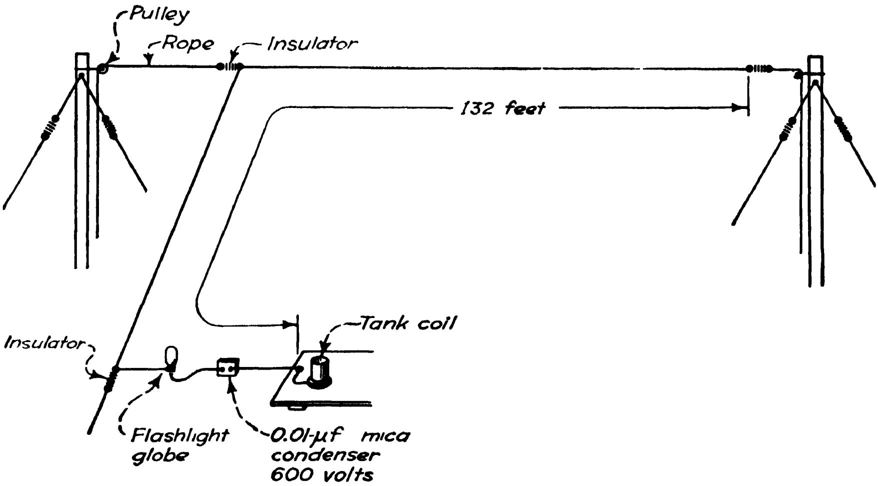


FIG. 488. The end-fed antenna is a half-wave in length. Connect it to the tank coil through a blocking condenser to keep the plate voltage off the antenna.

PART 6: THE SIMPLEST ANTENNA—THE END-FED HERTZ

One of the simplest antennas you can build and an easy one to get into operation is the end-fed antenna. The end-fed antenna is simply a basic half-wave Hertz with one end brought directly to the transmitter and connected to the tank coil through a fixed coupling condenser.

This antenna can be built quickly and is easy to get into operation. It is a handy and a simple portable low-frequency antenna. It is a good antenna for the beginner to use.

How to build the antenna. Cut the wire to half a wavelength. This is 132 feet for 80 meters.

Attach an insulator at one end (see Fig. 488). Attach a second insulator where the part of the antenna nearest to the transmitter

will be attached to a support. Attach a third insulator near the end at which the antenna is connected to the transmitter.

How to adjust the antenna loading. Attach the end of the antenna wire to a clip. The antenna clip is moved along the tank coil to adjust the antenna loading. The antenna loading is increased by moving the tap toward the plate end of the tank coil. No adjustment of the antenna itself is needed, since it is already cut to length.

How to measure the antenna loading. You can touch a neon tube to point X (Fig. 489) to see whether there is radio frequency in the antenna. You can also connect a dial lamp in series with the antenna to show how it is loading.

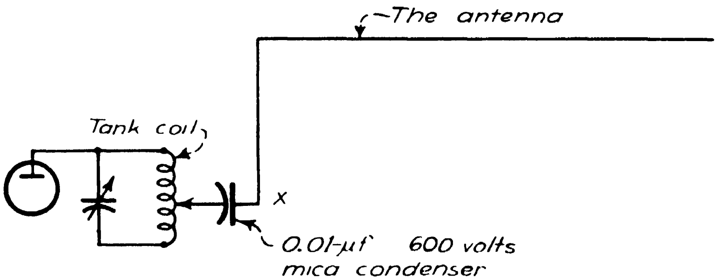


FIG. 489. The circuit for the end-fed antenna.

The plate-current meter is another good antenna-load indicator. When the final amplifier has been tuned to the lowest dip, it is in resonance with the oscillator. But as the antenna loads up, the plate current will rise.

You will find the best adjustment for the tap by watching the dial lamp in series with the antenna. Tune to find the setting that gives the greatest indication of the lamp.

Why it works. This is a simple half-wave Hertz antenna. The electron surges have been explained earlier in this chapter. The antenna is cut to length, so it is fixed-tuned. The blocking condenser is used so that the plate voltage of the final amplifier is left off the antenna for safety reasons.

PART 7: THE MARCONI ANTENNA

The Marconi antenna is basically the Hertz antenna, but the actual antenna itself is only one-quarter wavelength long. One end of the wire is connected to ground, which now acts as the other quarter of the antenna.

The Marconi antenna shown in Fig. 490 is simple to build. Its length of one-quarter wave includes the length of its feeder (the leadin) and the ground wire. The leadin is an actual part of the active radiating antenna. This antenna can be tuned at the set. The Marconi antenna is used mainly by broadcast and ship stations. It is sometimes used by amateurs when there is too little space to erect a Hertz half-wave type of antenna.

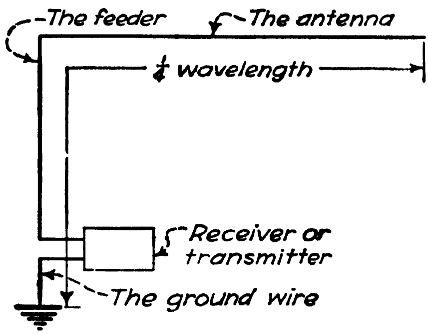


Fig. 490. The Marconi antenna is one-quarter wavelength long. The transmitter or the receiver is placed near the ground.

A good ground connection is needed for this antenna. When dry earth or the location of the station in a building makes it impossible to reach a good ground, a wire called a *counterpoise* is used to replace the ground connection. The counterpoise is a better conductor than most ground connections and so is more efficient than the ground.

The towers you have seen at broadcasting stations are often vertical Marconi antennas.

How to build the antenna. Build the antenna in the form of an inverted L, as in Fig. 490, or in the form of a T. Make the antenna any *odd* number of quarter wavelengths long.

Measure the length of the antenna from the ground to the end of the antenna. The ground wire from the set to the ground connection and the leadin from the antenna to the set are counted as part of the antenna.

The ground connection. A good ground connection must be used with this antenna. It may be a ground clamp attached to a cold-water pipe. Scrape the pipe clean and bright where the clamp is attached.

A six-foot rod driven into the earth makes a fair ground. This rod has not enough surface to be efficient.

Sheet metal or a copper boiler buried deep enough to be in earth that is always damp makes a good ground. The best ground has a large area in contact with permanently moist earth. Connect the set in the lead-in wire as near the ground connection as possible.

Keep the wire from the set to the ground short and direct. This antenna sends and receives somewhat better in a direction opposite to the free end of the wire. Build it with this end pointing away from the group of stations you want to receive from and send to.

How to couple the antenna to your set. Attach the antenna and ground leads to the blades of the antenna change-over switch as for the previous antennas you have studied. Attach two wires from the switch to the receiving set and two to the transmitter coupling coil. Use a loop of three turns of wire of the same size

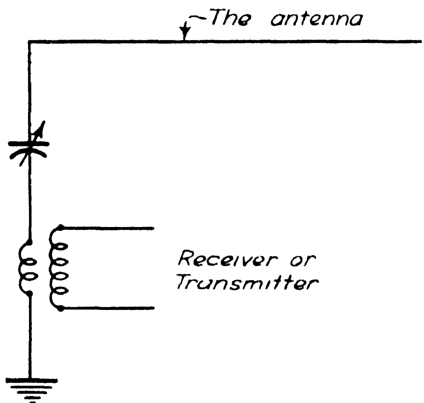


FIG. 491. The variable condenser will tune this antenna to a higher frequency.

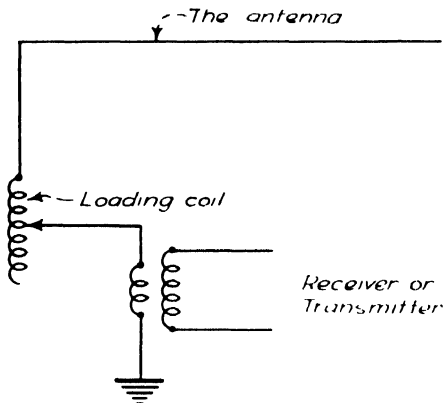


FIG. 492. If the antenna is too short its electrical length can be increased by means of a loading coil. It will then tune to a lower frequency.

and diameter as the plate tank coil to couple the antenna to the tank circuit. Arrange the coupling coil at the plate end of the tank coil so that it can be moved to change the coupling.

How to tune the antenna. Tuning can be done by using a variable condenser in series with the antenna, as shown in Fig. 491, or by means of a loading coil, as shown in Fig. 492.

The series condenser shortens the electrical length of the antenna so that it can be operated at higher frequencies. The coil increases the electrical length so that the antenna will operate at lower frequencies.

How to load the antenna for transmitting. Read the plate milliammeter before you couple the antenna to the set.

Move the coupling coil toward the tank coil until the plate current rises to several times what it was before the antenna was

coupled to the set. By still closer coupling more current will be drawn, but the plate of the tube will heat. When the plate heats, the set is operating inefficiently.

Why it works. The Marconi antenna uses the ground as half of the antenna. Surges reaching the ground rebound as in the half-wave Hertz. The timing of the rebound is such that the earth acts as a wire a quarter wave in length.

PART 8: THE COAXIAL CABLE

What is the coaxial cable? The coaxial cable, which is simply a copper wire or a small tube running through the center of a larger tube, as in Fig. 493, is quite similar to a two-wire transmission line. The outer tube is grounded and acts as a shield for the inner wire. The inner wire is separated from the outer tube by ceramic or plastic spacers placed every few inches.

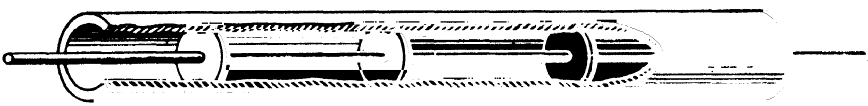


FIG. 493. This is a cutaway view of a section of coaxial cable. Note the center-wire conductor and the insulators spaced through its length. Other types of coaxial cable use different constructions.

The diameter of the cable and the thickness of the copper depend on the power the cable handles. For broadcast use, with powers up to 2000 watts, the cable may be $\frac{7}{8}$ inch in diameter with a $\frac{1}{4}$-inch copper tube for the inner conductor. This type of line is safe to handle because it is grounded. You will get no radio-frequency burns from handling it. Larger cable is used for higher power.

The line is filled with dry air or dry nitrogen gas under a few pounds pressure. This prevents the collection of moisture, or "sweating," inside the cable.

The coaxial cable may be run underground because there are no problems of insulating the conductors as there would be if a two-wire line were used.

What are some applications of the coaxial cable? In a mobile transmitter, where the feeder from the final amplifier to the whip antenna must pass through the car body, insulating is a problem. This is easily solved by the transmission line.

Note how the coaxial cable resembles the Hertz half-wave center-fed antenna and its half-wave twisted pair feeders (see Fig. 485).

Here, the coaxial cable takes the place of the feeders, the outer cable of one feeder, the inner cable of the other.

The case shown uses a quarter-wave antenna. The feeder can be any length, and the ground is the other quarter wave. The antenna must be cut or adjusted to the exact length for the frequency on which it will operate.

Questions

1. How long is the Marconi antenna when measured in wavelengths?
2. How is the actual length of a Marconi antenna related to the wavelength on which it transmits or receives best?
3. Is the Marconi antenna highly satisfactory for short-wave transmission?
4. Compare the coaxial cable to a transmission line.

CHAPTER 24

THE VERY HIGH FREQUENCIES

The interest of all radiomen and the whole world has, in the last few years, been focused on the higher frequency end of the radio-frequency spectrum. It is the mystery area in which the demands of the Second World War caused a generation of technical development to be crowded into a few short years. In this chapter you will learn something about the action of radio circuits at these higher frequencies.

In this chapter you will learn about the following things:

PART 1: WHEN RADIO MOVES INTO THE HIGH FREQUENCIES

The action of radio waves at different frequencies. Radiomen have long known that as radio waves increase in frequency, their action gradually changes. The most powerful commercial radio stations in use prior to the First World War used very low frequencies to send messages across the oceans. They operated at 20,000 meters, or frequencies of about 15 kilocycles. The stations that started radio broadcasting in the early 1920's operated on about 360 meters. Later, the frequency band between 550 and 1500 kilocycles (545 to 200 meters) was assigned for all standard amplitude-modulation (a-m) broadcasting. In the 1920's the fre-

quencies above 1500 kilocycles (below 200 meters) were thought to be useless and were handed over to the amateurs. The amateurs developed circuits, equipment, and antennas. They experimented and found that the supposedly useless short-wave (high-frequency) bands down to about 10 meters (30 megacycles) were valuable for reliable long-distance communication.

Names of frequency bands. At the time when these so-called *high frequencies* came into general use for long-distance commercial circuits, still higher frequencies were thought to have little value and, as before, were turned over to the amateurs. These were first called the *ultrahigh frequencies*, but they are now usually called the *very high frequencies*. At present, the different frequency bands are listed by the Federal Communications Commission as shown in this table:

Band	Abbreviated	Frequencies	Used by
Very low	vlf	10–30 kc	
Low	l-f	30–300 kc	
Medium	m-f	300–3000 kc	Broadcast
High	h-f	3–30 mc	Amateur
Very high	vhf	30–300 mc	f-m amateur
Ultrahigh	uhf	300–3000 mc	
Superhigh	shf	3000–up mc	

Circuits which worked well at lower frequencies became eccentric when operated on the very high frequencies. They often would not work at all. Or they might work well at first and then develop irritating and seemingly hopeless "bugs." The sets used by the early experimenters near 5 meters (60 megacycles) were at first a headache. (The old 56- to 60-megacycle 5-meter amateur band has been reassigned by the Federal Communications Commission. The new band is 50 to 54 megacycles.) The operation of these sets was erratic. It was found that the length of wires between the tube and the tuning circuit was very important and that they must be kept as short as possible. An oscillator which would not work at all might go into smooth, steady oscillation when the wires connecting the A battery to the filament of the tube were shortened 1 inch.

Tuning circuits became tiny. However, experimenting went on. No self-respecting radio amateur or his big brother, the radio-

research engineer, would admit that such problems were beyond solution. Coils were made smaller; typical coils were from 1 to 10 turns ½ inch in diameter, wound with No. 14 or 16 enameled wire. At 144 megacycles, parallel-rod transmission lines were used instead of coils in the oscillating tank circuit. Tuning condensers were reduced in size, and they were made with fewer plates.

Insulation problems. Insulation on tube bases and sockets and throughout the circuit became a problem, because the phenolic type of insulation, then widely used for the lower frequencies, proved to be a poor insulator at the very high frequencies. Very high frequency currents could be seen in the dark tracing glowing lines as they blistered their way across the surface of the insulator, which at these frequencies acted as a conductor.

Ceramic insulation became important. Steatite and high-grade porcelain came into use for tube bases, for the insulation of tuning condensers, and for standoff insulators.

What tubes are used for the very high frequencies? Tubes had to be specially designed. The distance between elements had to be made smaller, because in standard-sized tubes the distance between cathode and plate is so great that electrons require nearly as much time to cross from cathode to plate (this is called *transit time*) as a very high frequency surge requires to make a round trip through the tuning circuit. The length of the wires and element supports in standard tubes is often longer than the wire in the tuning circuit. This forced the development of the tiny acorn tube and many other special tubes.

What antenna is used? The antennas commonly used were and still are the familiar Hertz half-wave types. They are, of course, shorter in length than the Hertz antennas that are used at low frequencies. A 6-meter (50-megacycle) antenna is only about 9 feet long, a 2-meter (144- to 148-megacycles) antenna about 3 feet long. Directional antennas and arrays are easy to build and use because they are short.

PART 2: THE ACTION OF VERY HIGH FREQUENCY RADIO WAVES

Somewhere near 6 meters (50 megacycles) a radio wave begins to act like a light beam. This limits the range of sets of ordinary power to operation over line-of-sight, or visual, distances. This means that you can operate only as far as you could see if you

yourself were at the height of the antenna. In practice, however, the distance you can operate extends a little beyond the horizon.

The wave normally acts much like a light wave. While it is stopped by any solid object, the wave will bend, or refract, to a degree. It will bend over a hill, and some reception will be obtained in the first valley beyond, but seldom over a second hill.

High power makes possible a better coverage than does low power. A low-powered station will dissipate its energy within a short distance, while radio waves from a powerful station will travel farther and cover a larger area.

Waves act like light waves. The radio wave is found to be stopped by buildings and hills or other obstructions just as a beam of light is stopped. Suppose that an experimenter places a walkie-talkie operating on 6 meters (50 to 54 megacycles) on the bench in his shop and sends a friend across the lot with a similar set. The two keep up a running conversation. But when the friend walks around a neighbor's house, his voice fades out in the set in the shop (see Fig. 494). After tinkering with his set for a few minutes, the friend steps back into the lot to shout back to the experimenter in the shop. Imagine his surpise to hear the experimenter calling over the walkie-talkie, asking what is wrong. As long as the two sets were within sight of each other, they operated, but any building between the two sets immediately stopped the waves.

Waves can be reflected. The experimenter and his friend discover another interesting effect, that of wave reflection. As the friend walks down the street with the portable set, he passes several houses. He expects to hear nothing until he passes these houses and reaches the field beyond, where he will again be in sight of the shop.

However, he is surprised to hear the experimenter's voice after he has passed the first house. He walks on, talking back to the shop, but soon the voice again fades out. Walking back and forth, he finds that he can hear from the set in the shop only in a certain area. This proves to be the area in which the radio wave is reflected from a house on the opposite side of the street (see Fig. 495).

This reflection of very high frequency waves was used by engineers building the San Francisco–Oakland Bay Bridge. They planned a two-way communication system between the engineer-

ing headquarters in San Francisco and the various construction headquarters at the pier foundations on the other side of Yerba Buena Island.

A glance at a map of San Francisco Bay shows that lines drawn from the station on Telegraph Hill in San Francisco to the piers on the Oakland side of Yerba Buena Island pass through the

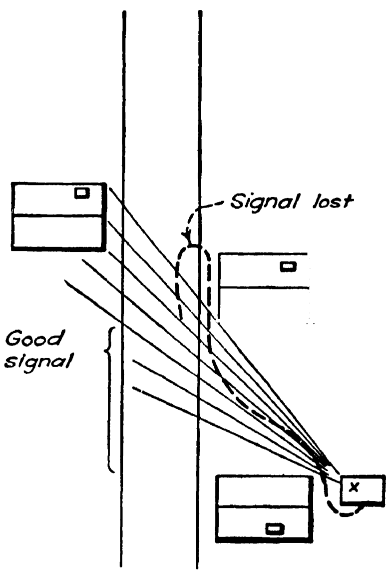


FIG. 494. The walkie-talkie found a radio shadow. Had higher power been used the signal might not have been lost.

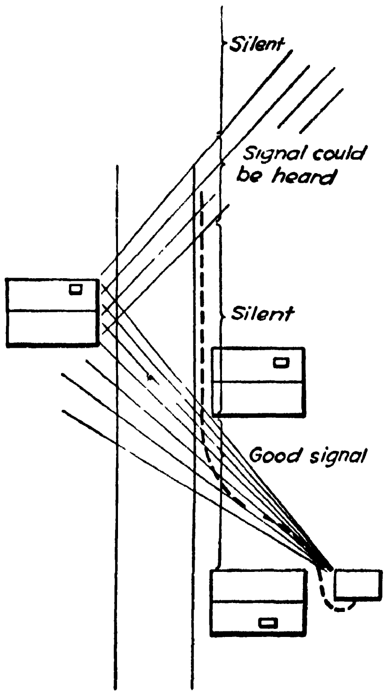


FIG. 495. The walkie-talkie also found that radio waves at very high frequencies could be reflected.

island. The island blocked direct contact between Telegraph Hill and the radio sets on these piers. But by swinging their directive antennas, the engineers on Telegraph Hill were able to establish contact with the piers. The radio waves, reflected from buildings or hills in Oakland, reached the piers by an indirect path, and so communication was established.

In the classroom or in your home workshop, you will enjoy setting up a very high frequency oscillator and experimenting with different types of directive antennas.

How Radar Speedmeters Work

Modern cars and highway speeds require modern traffic safety controls. Police in many communities are using speed-checking equipment similar to this Doppler radar transceiver to promote accurate and reliable speed control.

PART 3: COMPARISON OF ORDINARY SETS AND VERY HIGH FREQUENCY SETS

When you place a short-wave set and a very high frequency set side by side and examine each, you find that they have very few fundamental differences. Both use the same basic transmitter and modulator circuits and the antennas are based on the same principles. The very high frequency set uses smaller tuning coils and tuning condensers, and its antenna is very short.

Developments in tube construction make many standard receiving tubes usable in very high frequency circuits. Recently developed tubes with very low interelement (inter-element) capacity and well-shielded leads inside the base may be used in very high frequency sets.

Standard tubes work well up to the 144-megacycle band. But for frequencies of 235 megacycles or 420 megacycles, the acorn tubes or the midget tubes similar to the 9000 series must be used. A new type of construction used in the so-called *lighthouse tube* makes possible the use of this tube on still higher frequencies.

Above the very high frequencies, in the microwave region, special tubes such as the klystron and the magnetron must be used. These tubes operate on radically different principles.

PART 4: THE VERY HIGH FREQUENCY TRANSMITTER

The transmitter for the higher frequencies uses the same circuits that you studied in Chapter 20, "Power Oscillators and Amplifier Circuits." The tuned-plate tuned-grid circuit is used. The oscillator often uses a push-pull circuit.

A low-powered experimental very high frequency transmitter for a 50- to 54-megacycle band will need an oscillator and a power amplifier to operate over any distance, but a transmitter for the 144- to 146-megacycle band will work with only an oscillator. These sets will only operate over a distance of a few miles. A single tube will modulate either transmitter.

If the tubes mentioned above are not used, special power tubes make good very high frequency oscillators and amplifiers. They must either have small elements or be specially designed for use in high-frequency circuits. The tuning circuit for the 144-megacycle band uses a two-plate midget tuning condenser and coils of one or

two turns of No. 14 or 16 enameled wire wound on a dowel $\frac{3}{8}$ inches in diameter.

For frequencies above 144 to 420 megacycles, the parallel-rod type of tuning circuit is more efficient than small coil and condenser circuits. Steatite or other ceramic insulation is required. Polystyrene and similar high-frequency-resistant plastics are also used for insulation. They are easy to work and are excellent for set construction.

Special high-frequency chokes are required. Mica condensers must be used rather than the paper condensers. The tuning circuit must be shielded to prevent body capacity, which is very bothersome at high frequencies.

Question

Make a list of differences between long- and short-wave sets.

How to Build and Wire a 144-megacycle Oscillator

Build this set on a large baseboard. Mount two ceramic lock-in sockets on a plastic or pressed-wood panel (see Fig. 496). Wire as shown in Fig. 497.

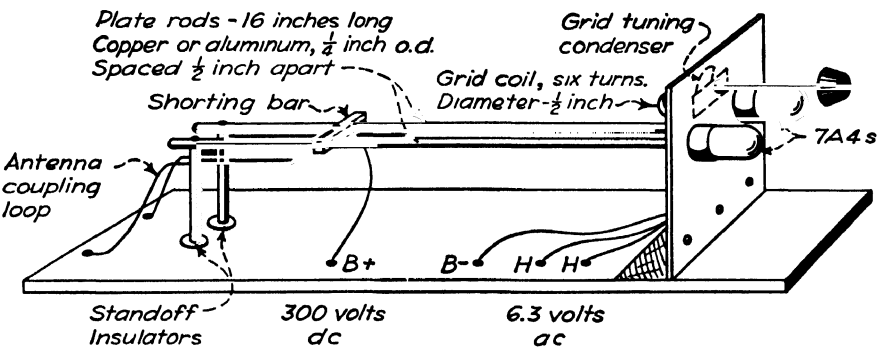


FIG. 496. The board layout for the very high frequency transmitter.

Make the plate rods. Cut two pieces of copper tubing of $\frac{1}{4}$-inch outside diameter to a length of 16 inches. Solder the copper tubes directly to the tube-socket connections. Use only rosin-core solder. Use no paste flux, because it is a good conductor at very high frequencies. Support the rods on polystyrene or ceramic standoff insulators. Space them accurately $\frac{1}{2}$ inch apart, center to center. Errors which are slight at low frequencies are much larger at high frequencies.

Make the grid coil. Make this coil of No. 14 enameled wire. Wind two turns on a $\frac{3}{8}$-inch rod, or dowel. Space the turns so that the coil is about $\frac{3}{4}$ inch long. Allow about $\frac{1}{4}$ inch on the ends of the turns to solder to the tube socket. Cut off any surplus wire. Use ceramic-insulated tuning condensers, since high frequency easily leaks through ordinary insulation.

Make the coupling loop. Form a small U-shaped coupling loop of No. 14 enameled wire. Space the sides of the U $\frac{1}{2}$ inch apart. Mount the loop near the end of the plate rods as a coupling loop

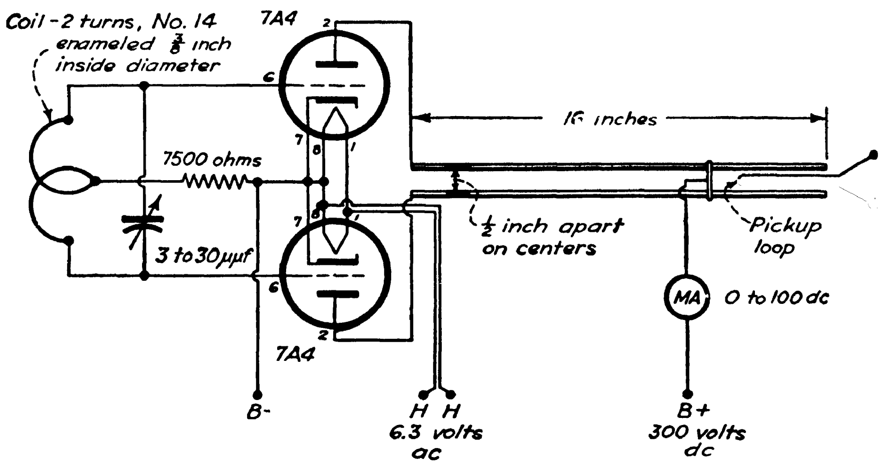


FIG. 497. The circuit diagram of a very high frequency transmitter to operate on 144 megacycles.

(see Fig. 496). This loop is used to couple the transmitter to an antenna or to a dummy antenna.

Note, in Fig. 497, that the filament-heater wires are grounded.

Make the dummy antenna. You can connect a 125-milliampere dial lamp across the pickup loop to act as an untuned dummy antenna. If the loop is coupled too closely to the plate rods, the lamp may burn out. Bend the loop away from the rods if the lamp burns out.

How to Build and Wire a Modulator

Build this set on a small baseboard. The jack for the carbon microphone is at the left as part of the microphone circuit (see Fig. 498).

Use a microphone-to-grid input transformer in the grid circuit.

Use a 10- to 30-henry 50-milliampere choke for the modulation transformer. None of the rest of the circuit is unusual. Wire the

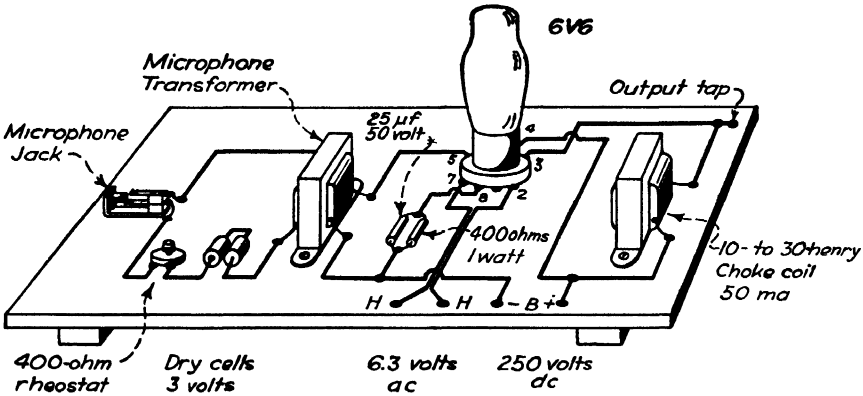


FIG. 498. Layout of parts for the modulator to be used with the very high frequency transmitter for a low-powered radio telephone.

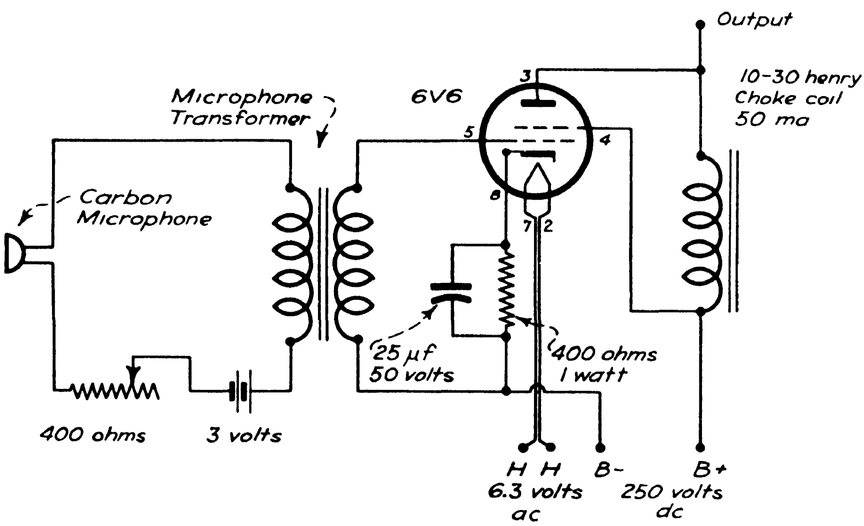


FIG. 499. The circuit diagram for the modulator.

modulator as shown in Figs. 498 and 499. The circuit of the complete set is shown in Fig. 500.

How to Operate It

High-frequency equipment requires greater care to tune and to operate than do low-frequency sets. This is true for several reasons. Slight changes in the spacing of the parallel wires, vibra-

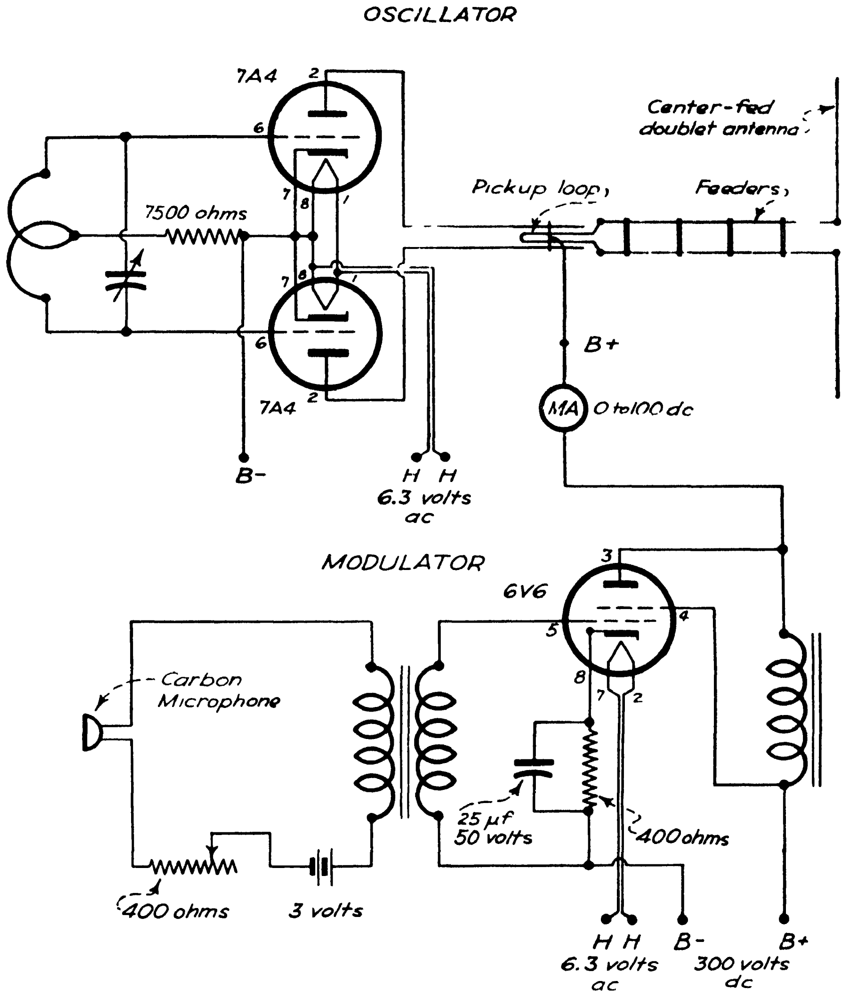


FIG. 500. The diagram of the complete circuit of the low-powered very high frequency radio-telephone transmitter.

tion, or a part slightly bent because of handling, which would ordinarily be unnoticed, may seriously affect the operation of this set.

Step 1. Set the shorting bar near the end of the plate rods.

Step 2. Turn on the B battery.

Step 3. Tune the grid tuning condenser until the plate meter dips to the lowest point (about 20 milliamperes). The oscillator

is now in operation at an unknown frequency. The frequency may be measured by means of the Lecher wires described in Part 5 of this chapter.

Step 4. You can change the frequency by moving the shorting bar on the plate rods. To raise the frequency, you move the bar *toward* the tubes; to lower the frequency, move *away* from the tubes.

Step 5. Readjust the grid tuning after you move the shorting bar as explained in Step 3. If the set fails to oscillate, try changing the size of the grid coil. Tune this coil by stretching it so that the turns are farther apart or closer together. If this fails to make the set oscillate, either add a turn or cut off a turn.

Step 6. Connect the antenna to the coupling loop that you built on the board to act as a load. Adjust the coupling between the antenna and the oscillator by bending the pickup loop. The plate meter should show a 15-milliampere increase as the antenna absorbs power from the oscillator. Retune the grid circuit to the lowest dip.

Why It Works

The explanation of this very high frequency oscillator is the same as that of the tuned-plate tuned-grid oscillator explained in Chapter 20. The action of the modulator is explained in Chapter 22.

The parallel plate rods act as the tuned plate circuit. You tune them by adjusting the position of the shorting bar.

Instead of tuning by changing the capacity of the variable condenser, as in a standard circuit, you move the bar, which changes the actual length of the rods. This has the same effect as adding or subtracting turns to the coil.

PART 5: LECHER WIRES—HOW TO MEASURE WAVELENGTH

Lecher wires, two long parallel wires coupled to a transmitter, are a form of transmission line useful for measuring the wavelength of a high-frequency oscillator. Electron surges in these wires produce points where the voltage is strong and other points where it is zero. (On long Lecher wires you will find several similar sets of points.) These points, which are spaced at regular distances, are caused by standing waves. *Standing waves* are

points of maximum and minimum current, or voltage. The distance between two nodes or two loops is a half wavelength. From this distance, measured in meters, you can readily determine the wavelength at which your oscillator is operating. Knowing the wavelength, you can compute the frequency.

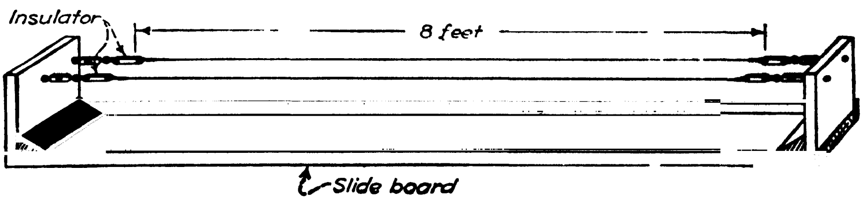


FIG. 501. The Lecher wires used to measure very high frequencies. The wires are mounted on a slide board so that a meter board can be moved under them to measure standing waves when the wires are used in later experiments as a transmission line.

How to build and wire the set. Stretch two No. 14 bare copper wires 8 feet long between supports (see Fig. 501). Place an insulator at each end of each wire. Space the wires $2\frac{1}{2}$ inches apart. The wires must be accurately spaced to operate correctly.

Make a shorting bar of No. 14 bare copper wire. Form each end of this wire into a loop (see Fig. 502). The shorting bar must be arranged so that it will slide along the Lecher wires and will keep the spacing of the wires the same while maintaining good contact at all times.

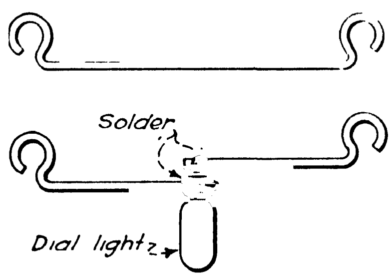


FIG. 502. Shorting bars for the Lecher-wire experiment. The dial light, soldered in the bar, shows nodes and loops by its glow.

How to operate it. Place a milliammeter in the plate circuit of the oscillator. Attach two wires from the pickup coupling loop on the oscillator to the Lecher wires. Turn on the very high frequency oscillator. Place the shorting bar across the two Lecher wires at the insulators (see Fig. 503).

Use a yardstick or a piece of dry wood at least 2 feet long to slide the shorting bar down the Lecher wires. Slide the shorting bar slowly along the wires until the milliammeter shows a sharp dip. Move the shorting bar back and forth until you have accu-

rately determined the position at which the meter shows the dip. Mark this point with a piece of string tied around the wires.

Now slide the shorting bar further along the Lecher wires until a second point is found at which the meter shows a sharp drop in plate current. Find the position of this point accurately, as before, and mark it with a string. These are *nodal points*.

How to determine the antenna length and frequency. Measure the distance between the nodal points, where the meter shows a sharp drop in plate current. The distance between two of these points is equal to half the wavelength on which the oscillator is

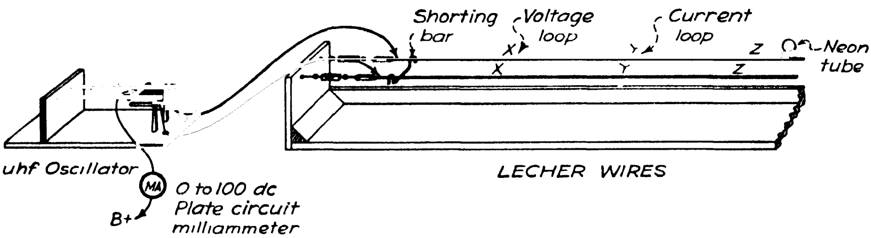


FIG. 503. Couple the very high frequency oscillator to the Lecher wires. The distance between the loops shows the wavelength on which the oscillator is operating. Figure the frequency from the wavelength.

operating. This will be the length in inches of the antenna which you use for this transmitter.

You can compute its frequency by using the formula

$$\text{Frequency in megacycles} = \frac{5906}{\text{antenna length in inches}}$$

Questions

1. Why is it necessary to use rosin-core solder on very high frequency sets?
2. What fraction of a wavelength is the distance between two points on the Lecher wire at which the meter reading dropped?
3. How can you locate the reflected waves on the Lecher wire?

PART 6: AN ANTENNA FOR VERY HIGH FREQUENCY SETS

You may use the center-fed doublet antenna for your very high frequency experiments, because it is an easy antenna to build and adjust. It is connected to the set by a transmission line. For regular installations a special cable designed for this purpose is used. In commercial work a coaxial cable is used for the transmission lines.

Make the doublet antenna in two halves of equal length (see Fig. 504). If you use them in the laboratory, the length of these

two halves should be adjustable. Use two adjustable whip-type car antennas, or make your own antenna of tubing with sliding rod inserts. In this experiment the total length of these antennas should be about 24 inches. When this length of antenna is about 20 inches, it will operate in the 144- to 148-megacycle band. This antenna will draw power from the oscillator. Mount the antenna rods on standoff insulators set on an upright about 5 feet high with a base which will prevent it from tipping over when in use.

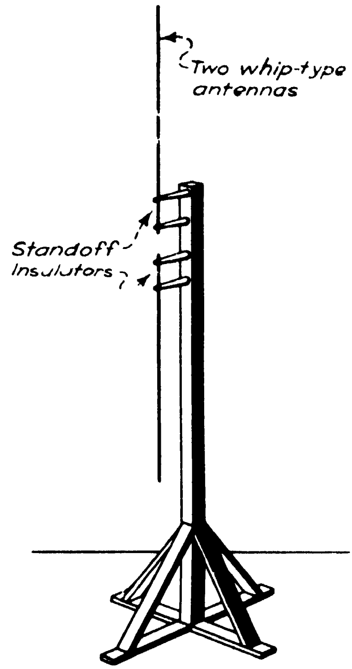


FIG. 504. Mount the antenna on a stand for use in these experiments.

PART 7: A TRANSMISSION LINE FOR THE VERY HIGH FREQUENCY TRANSMITTER

It is often desirable to place the antenna at some distance from the transmitter. The feeder, or transmission line, which carries power from the transmitter to the antenna may be of considerable length. This line must be built and used correctly so that the energy you put into it at the oscillator will reach the antenna. It must also be properly coupled to both antenna and transmitter, or part or all of this power will be lost.

You can use a two-wire transmission line or a coaxial cable. Properly designed lines are very efficient, and most of the power fed into the line will be delivered to the load at the other end. The load in this experiment may be an antenna or a resistance. The power from the oscillator, transferred to the antenna by the transmission line, is radiated as radio waves.

You can tell how efficiently the line is operating by checking for standing waves. Standing waves in a transmission line are an indication that part of the power in the antenna is feeding back into the line by reflection.

Make the transmission line. Make the line of two No. 20 enameled wires spaced 2 inches apart on centers. The length of the line is not critical. For experimenting in the laboratory, the

line may be from 10 to 20 feet long. For attaching your transmitter to an outdoor antenna, a longer line will be needed. Cut spacers of $\frac{1}{8}$-inch-thick Lucite, $\frac{1}{2}$-inch wide by $2\frac{1}{2}$-inches long. Drill two holes 2 inches apart for the line wires.

Thread the wires through the spacers. Separate the spacers by about 3 feet. A drop of model-airplane cement will hold the spacers in place on the wires.

Check for standing waves. Now learn how to connect the line to the antenna and how to adjust the hookup so that power is transferred to the antenna. When you selected the size of the wire and its spacing, you determined the impedance of the trans-

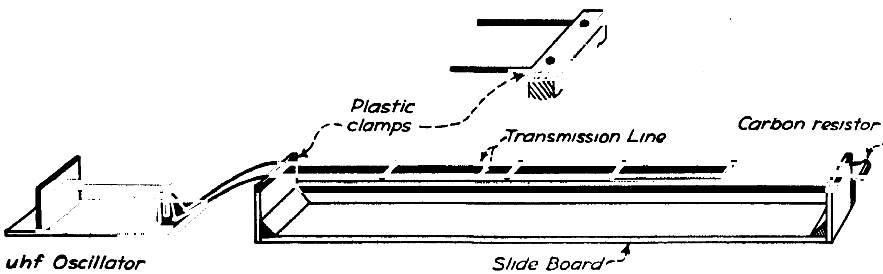


FIG. 505. Attach the transmission line to the slide board for the standing-wave test. Note the plastic strips used both to insulate and to clamp the wires of the line to the slide board during the test.

mission line. It is easy to find the actual value of this impedance by a simple experiment.

You can find the impedance of the line by connecting noninductive resistors to the end of the transmission line in place of the antenna. When you have the correct resistance connected to the end of the line, the maximum power will be transferred from the transmitter, through the line, to the resistor, where it will be diss'pated as heat. There will be no standing waves in the line.

When an incorrect resistance is attached to the end of the line, power is reflected back into the line, and it creates standing waves. A meter, described below, may be used to show the presence of standing waves on the line.

How to Hook Up the Experiment

Step 1. Attach one end of the transmission line (of any convenient length) to the high-frequency oscillator. Attach two clips to the antenna end of the transmission line.

Step 2. Try attaching different 5-watt carbon resistors to the clips at the end of the line as you run this test (see Fig. 505). You will need one of each of several sizes: a 300-ohm, a 400-ohm, a 500-ohm, and a 600-ohm resistor.

Step 3. Start with the lowest value, and try each resistor until the test meter described below shows no standing waves on the line.

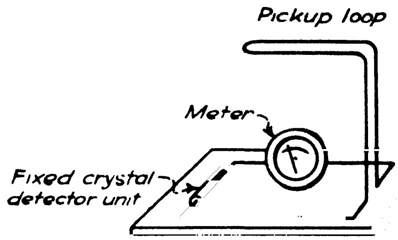


FIG. 506. The board layout for the test meter to be used for the checking of the transmission line for standing waves.

How to Build and Wire the Test Meter

A test meter is needed to check the transmission line for standing waves. It is a small receiving set using a crystal rectifier and a 0 to 1 direct-current milliammeter to indicate the energy picked up from the line by a pickup loop

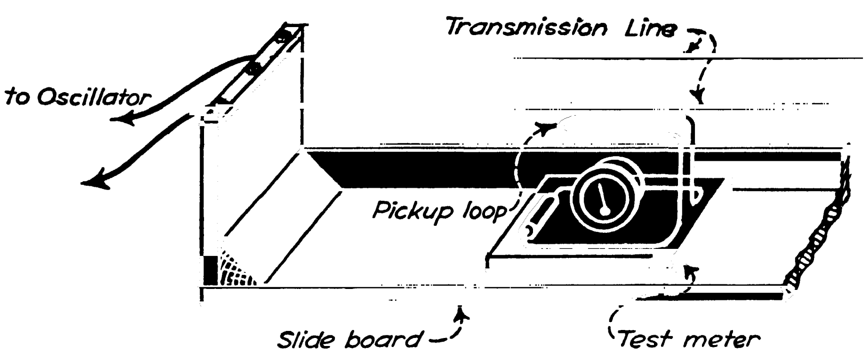


FIG. 507. Set the test meter under the transmission line on the slide board to run the test. Adjust the height of the pickup loop to get the desired meter-reading range. Move the meter board along the slide board to find the nodes and loops of the standing waves.

Mount the crystal and a 0 to 1 direct-current milliammeter on a baseboard as shown in Fig. 506. Make the pickup loop of No. 14 enameled wire. Wire the meter as shown in Fig. 506. Build a slide board for the meter pickup as shown in Fig. 507. This will keep the pickup loop at a uniform distance from the wires as you move the meter along under the line

How to Operate It

Step 1. Set the test-meter slide board under the transmission line as shown in Fig. 507. Place the test-meter line on the slide board.

Step 2. Attach the end of the transmission line to the pickup loop on the oscillator. Turn on the oscillator.

Step 3. Adjust the coupling loop on the meter by bending it upward or downward until the meter reads full scale—1 milliampere. The loop should be about 3 inches below the transmission-line wire. If too near the wires, the meter will get too much current, and both the meter and the crystal may be burned out. A fuse on the meter is a sensible protection. If the loop is too far from the wires, the current it picks up will be too weak to give full-scale reading.

Move the meter board along the slide.

Step 4. Try different resistors at the end of the transmission line until the meter reading is the same all along the line.

Why It Works

When you find a resistance where there are no standing waves on the line, the oscillator is delivering all its power to the resistor. The resistor is dissipating the radio-frequency power as heat.

If you find that a 500-ohm resistor makes a flat line, one that has no standing waves, then you are safe in assuming that the approximate impedance of the line is 500 ohms.

PART 8: HOW TO COUPLE AN ANTENNA TO YOUR VERY HIGH FREQUENCY OSCILLATOR

When you couple an antenna to your oscillator, you can talk around town with this very high frequency set. Remember that this may only be done legally if a licensed radio amateur is in charge of the station and if the equipment is licensed by the Federal Communications Commission.

Now attach the doublet antenna described earlier to the end of the transmission line (see Fig. 508). Adjust the length of the two halves of the antenna until they draw power from the transmitter. The antenna should be about 20 inches in over-all length. It will then operate in or near the 144- to 148-megacycle band.

If it is too long or too short, it will reflect energy back into the line, and only part of the power developed by the oscillator will reach the antenna. This condition is shown by standing waves on the transmission line.

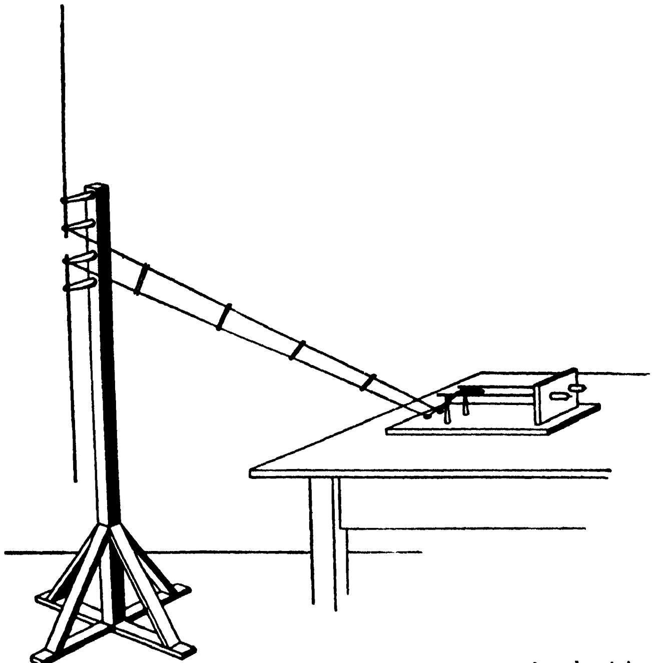


FIG. 508. Couple the oscillator to an antenna by means of a short transmission line.

Let us now study the transmission line and learn something about its action and how it can be adjusted to transfer most of the power from the oscillator to the antenna.

PART 9: HOW TO MAKE A DIRECTIONAL ANTENNA

If you were to make a field-strength meter and take readings on it as you walked outward from a vertical antenna, you would find that the field pattern was uniform around the antenna. The strength of the radio waves diminishes rapidly as you move away from the antenna, but the field strength for a vertical antenna at a distance of 20 feet from the antenna is the same in any direction.

However, instead of spreading the energy in all directions when you wish to talk to a definite station, you can arrange your antenna

so that most of the energy in the radio waves is concentrated in one direction.

One way to do this is to place a second antenna rod near it (see Fig. 509). If a second antenna slightly *longer* than a half wave is placed parallel to the main antenna and slightly less than one-quarter wave behind the first antenna, it will act as a reflector. It is called a *parasitic reflector* because it reradiates energy from

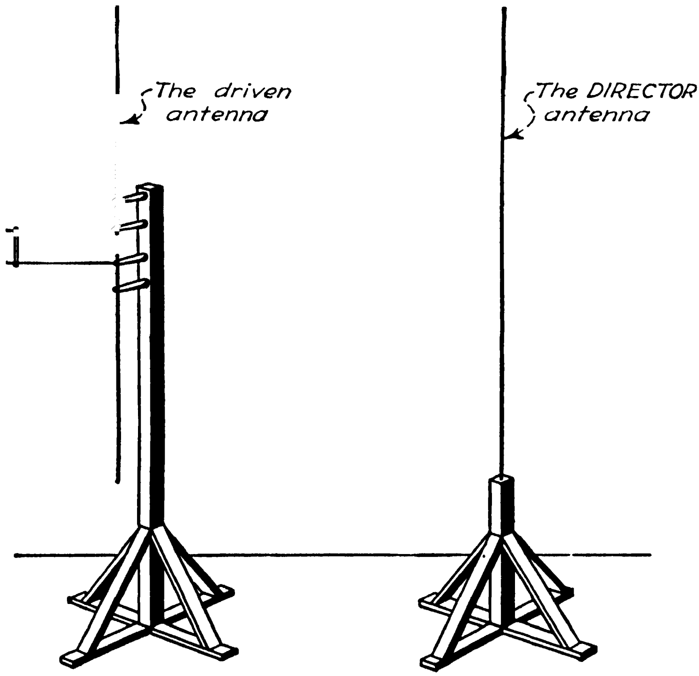


FIG. 509. Set a director near the antenna to make it into a directive or beam antenna.

the main antenna to produce reflections. It will reflect the radio wave as shown in Fig. 510.

But when placed in front of the antenna, as shown in Fig. 511, the second antenna acts as a *parasitic director*. The director antenna is slightly *shorter* than a half wave. Note the direction of the resulting radio waves.

How to Operate It

Set up a reflector, and learn its action in strengthening the wave in one direction.

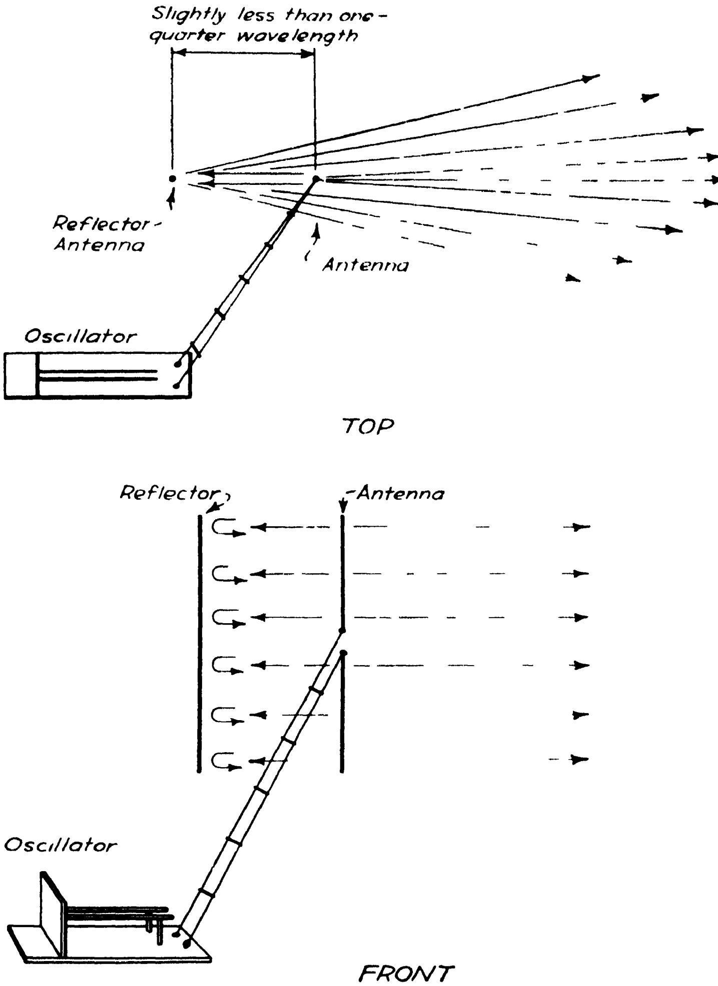


FIG. 510. Place a second antenna slightly less than one-quarter wave behind the main antenna, and it acts as a parasitic antenna which uses energy received from the first to reflect the radio waves in the direction shown in the drawing.

Step 1. Set the reflector near the antenna on the side *away* from the direction in which you wish the antenna to operate (see Fig. 510).

Step 2. Move it away from the antenna 2 inches at a time. The position of the reflector is about one-quarter wave behind the antenna for best results. This position is important.

Step 3. Check with the field-strength meter until the radio waves are stronger on the side away from the reflector.

Step 4. When this occurs, measure accurately the distance between the rods. Find out by what fraction of a wavelength the two are separated. Try the same experiment for a director rod.

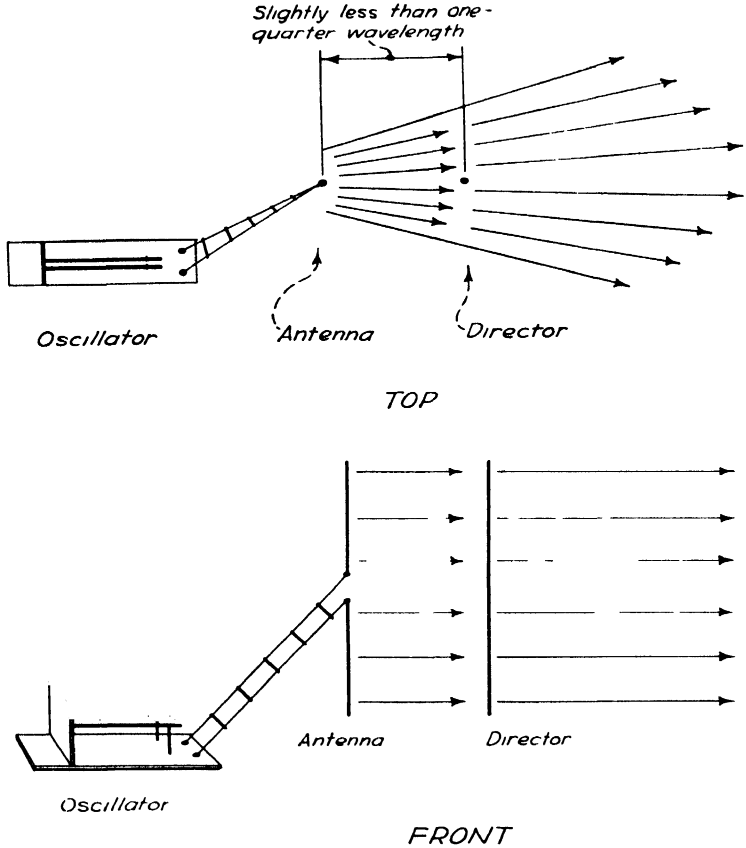


Fig. 511. Here the parasitic antenna is set in front of the main antenna where it acts as a director to collect and direct the radio-wave energy in one direction.

It is placed on the side of the antenna *toward* the direction in which you want the strongest radiation from your antenna. Proceed as explained for the reflector. You can get still better results by using both a reflector and a director together.

Why It Works

Energy radiated from the driven antenna (the one to which the transmission line is connected) sets up electron surges in the reflec-

tor. These surges in turn radiate radio waves. The waves from the reflector combine with the wave from the driven antenna to form a strong field of radiation, as shown in Fig. 510, on the side opposite the reflector. Radiation on the side facing the reflector is quite weak.

The same action occurs in the director antenna. It aids and strengthens the radio waves on its side of the driven antenna (see Fig. 511).

PART 10: HOW TO USE A FIELD-STRENGTH METER

This meter is a well-shielded one-tube receiving set built in a metal box. A short antenna picks up energy, and a meter reads

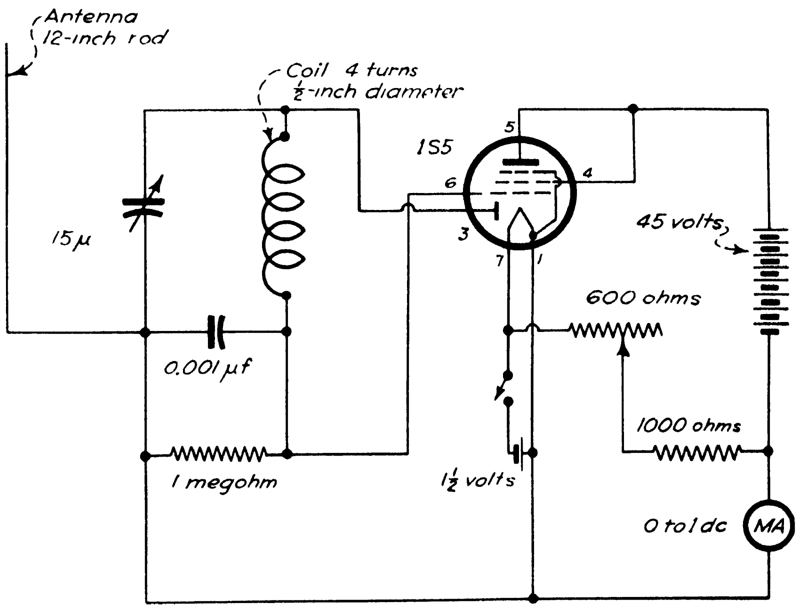


FIG. 512. The circuit diagram for the field-strength test meter.

the plate current flowing in the tube. This meter reading is used to plot a curve which shows the strength of the field around the antenna.

How to Build and Wire It

Mount the parts for the meter in a closed metal box. Mount the filament switch, the tuning condenser, the zero set resistor, and the meter on one face of the box.

The zero set resistor and the battery switch are insulated from the metal box (see the schematic diagram in Fig. 512).

Make the antenna of a light metal rod, or tube, $\frac{1}{4}$ inch in diameter and about 1 foot long, mounted on an insulated binding post or an insulated jack.

How to Operate It

Step 1. Attach the antenna and turn on the filament.

Step 2. Carry the field-strength meter some distance away from the antenna. Set the meter reading to zero by means of the zero set resistor.

Step 3. Take readings at definite distances from the antenna. Record these readings. You can later transcribe them on a piece of polar-coordinate paper.

Questions

1. Show how you can use standing waves to prove that your antenna is the right length.
2. Compare the construction of a transmission line for high frequencies with a line used for low frequencies.
3. Describe how to use a field-strength meter in checking the field strength around a vertical antenna.
4. What is the correct distance of the director from an antenna for obtaining the best directive results?
5. What are the differences between the construction of a test meter used for checking power in a transmission line and the construction of a field-strength meter?

PART 11: THE VERY HIGH FREQUENCY RECEIVER

Because high frequencies in a coil tend to make adjacent turns of a coil act like a condenser, a new type of coil must be used, one with space left between turns. Parallel rods can be used in place of a coil. The length of connecting wires between parts must be made as short as possible, because even a short wire may act as an uncontrolled oscillating circuit. These wires also have a capacity which cannot be controlled as can the capacity in the tuning condenser.

For this reason, the parts must be placed very closely together, and in many cases, the fixed condensers and resistors are soldered directly to the tube sockets.

Capacity of connecting wires outside the tuning circuit acts like a fixed condenser shunted across the tuning condenser. It reduces the amplification in that stage. Two ways to overcome this problem are to use the superheterodyne circuit, with its great selectivity, or the superregenerative (super-regenerative) circuit, which is highly sensitive and has high amplification. You will work with the latter circuit in this chapter.

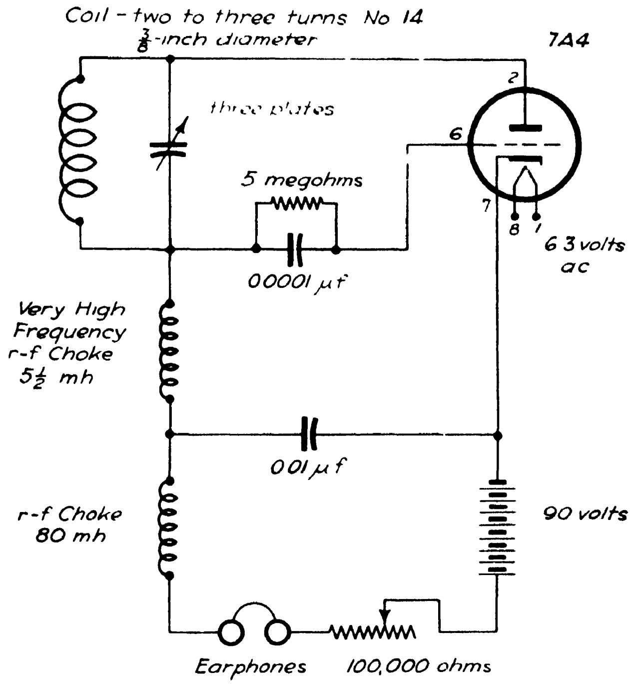


FIG. 513. The circuit diagram for the superregenerative receiver.

The superregenerative receiver uses a principle which extends the sensitivity and the amplification far beyond that of the regenerative circuit. This circuit is another developed by Armstrong.

How to build and wire the superregenerative receiver. Build the receiver on a small baseboard. Mount the parts on an upright piece of masonite as shown in the diagram. The tuning condenser must have ceramic insulation. Solder the coil directly on the condenser. Make the coil of two to three turns of No. 16 enameled wire. Wire the set as shown in Fig. 513.

Use a small ½-watt resistor for the grid leak and a small mica grid condenser. Note that one radio-frequency choke is a special

ultrahigh-frequency type. The other is an ordinary 80-millihenry receiver choke.

Use a regeneration-control resistor with attached switch to open and close the filament circuit.

All connecting wires in the tuning circuit and wires from this circuit to the tube must be as short as possible. While wires outside of the tuning circuit beyond the radio-frequency chokes are less important, they also should be kept as short as possible.

How to operate it. The operation of this set is very simple. With the cathode hot and the B voltage on, the set will go into superregeneration at once. If the set does not superregenerate, you will find some fault in the circuit.

Try changing the B voltage until you find a voltage at which your set will superregenerate over the entire tuning range of the condenser. This should be somewhere around 90 volts. Check the circuit carefully to see that the set has been properly wired. Superregeneration produces a steady, strong hiss in the receiver. If no hiss is present, the set is not operating correctly. You will find that the hiss stops as you tune the set to resonance with the signals you wish to hear.

See if any soldering paste or flux has melted and run down the soldering lugs onto the insulation on any of the parts. Ultrahigh-frequency currents follow this flux as if it were a piece of wire. It is common to find that this set will not operate because paste flux has been used and has run across the insulation, shorting out parts of the circuit. Avoid this trouble by using only rosin-core solder.

You may also find that changing the size of the antenna coupling condenser will allow the set to go into superregeneration.

Questions

1. How do you know when the set is superregenerating?
2. What are some ways for correcting the trouble when the set will not superregenerate?

Why it works. The regenerative type of receiver which you have used both in the long-wave and short-wave receiving circuits is extremely sensitive. Its sensitivity is brought about by feeding back energy from the plate circuit to the grid circuit. You will remember that the set is most sensitive when adjusted *just below*

the oscillation point. Here the signals are clearest and loudest; when you try to increase the volume still more, the set pops into oscillation and the signals become distorted. The nearer you can adjust your set to the oscillation point, the more sensitive your set will be.

Draw a sensitivity curve. Let us draw a curve in which a line shows the sensitivity of the receiver. We shall use the setting of our regeneration-control condenser as one base line and the sensi-

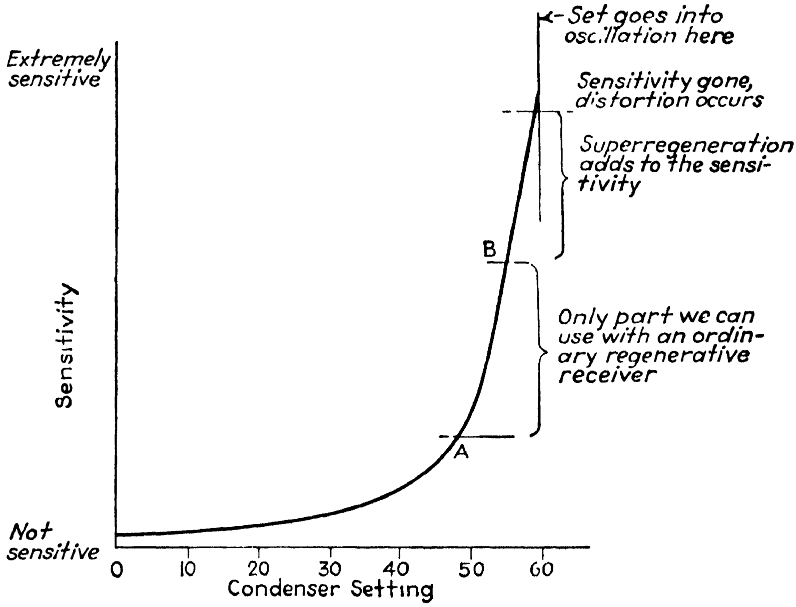


FIG. 514. The sensitivity curve for the superregenerative receiver.

tivity of the set as the other base line (see the curve in Fig. 514). You will notice that when you turn the control from 0 to about 40 there is very little sensitivity in your set. The height above the sensitivity line shows how sensitive this set is at any setting of the condenser. The part of the curve near the base line shows that at this condenser setting, the set is very insensitive. As the curve rises, it shows that the sensitivity of the set is increasing. As the curve goes up steeply, it shows that a very little motion of the regeneration-control dial is increasing the sensitivity very rapidly. You will notice that between 40 and 60 the sensitivity increases with extreme rapidity and that at about 60 the smallest

adjustment you can make on the condenser will throw the set into oscillation.

The part of this curve between lines A and B is the part you can use with the ordinary regenerative circuit. You will notice that you are able to use only a part of the sensitivity of this set because it will go into oscillation. You cannot adjust the set by the mechanical movement of turning the condenser dial and get anywhere near the maximum output of the set. When your regenerative receiver is operating close to the oscillation point, it is unstable. A surge of static or a loud signal will be enough to throw the set into oscillation. Therefore, you must back the control away from this point. You need some method which will allow you to operate close to the oscillation point and yet will prevent the set from spilling over into oscillation. This is done in the superregenerative circuit.

How does the superregenerative circuit work? This system of superregeneration uses a grid condenser and a high-resistance grid leak (5 megohms) to interrupt the oscillation of the superregenerative detector. This resistance is high enough to collect and hold electrons on the grid and to block the action of the tube periodically. This stops the oscillation of the tube at a frequency above 20,000 times per second and provides superregeneration.

What is quench frequency? There is also another electrical method of preventing the receiver from reaching the oscillating point. This new method uses a separate oscillator coupled to the superregenerative receiver. The job of the new oscillator is to prevent the receiver from going into oscillation and yet to allow the receiver to operate as near the oscillation point as possible.

In this new circuit, the control of regeneration is automatic. It is accomplished by coupling the separate oscillating circuit to the plate of the regenerative receiver. The oscillation point is now controlled electrically.

This *quench oscillator* is adjusted to operate at a frequency of 20,000 to 50,000 cycles per second. The quench oscillator is coupled to the receiver, so that its output reduces the plate current of the superregenerative receiver to a value below the oscillating point of 20,000 times per second. The result is that the signals in the receiver can build up to a maximum volume. Any distortion that occurs in this circuit is above audibility. Conse-

quently, the new circuit works at the most sensitive point on the curve. This type of receiver is far more sensitive than the ordinary regenerative receiver.

The fact that this circuit tunes very broadly is an advantage in the very high frequency band, because it allows you to tune across a comparatively wide band and pick up the signals you wish to hear. Interference is produced by this receiver because it is in continuous oscillation. It acts as a weak transmitter. This circuit defect is overcome by the use of the superheterodyne type of receiver.

Questions

1. Are you able to operate an ordinary regenerative set close to the limit of sensitivity?

2. Is it possible to adjust the set mechanically so that it will operate near the peak of sensitivity without its going into oscillation by itself?

3. Show how the quench frequency will permit the set to build up to the peak of sensitivity and then stop it just as it goes into oscillation.

Technical Terms

acorn tubes—Special high-frequency tubes which get their name from their shape.

director—Rods or wires placed in front of an antenna to assist in making it directional.

field-strength meter—A well-shielded portable receiving set used to measure the strength of the radio waves radiated from an antenna.

Lecher wires—A pair of spaced wires used to measure wavelength, or frequency.

microwaves—Waves in the superhigh-frequency region.

polystyrene—A plastic type of insulation.

quench frequency—The frequency set up in the superregenerative receiver which allows the circuit to operate very close to the point of maximum sensitivity without going into regeneration.

reflector—Rods or wires placed behind an antenna to reflect the radiated wave so that the antenna will radiate most of its energy in a desired direction.

steatite—A ceramic type of insulation.

superregeneration—Regeneration controlled by the action of the circuit, so that the receiver is made very much more sensitive than is possible with hand-controlled regeneration.

CHAPTER 25

FREQUENCY MODULATION

Through the years radio broadcasting has undergone great technical development and refinement. In the development from the crude set of the 1920's with its maze of wires and its elementary tuning system to the modern single-control console in a beautifully designed cabinet we have seen a host of improvements in tubes, circuit design, and speakers.

Nevertheless, in spite of all this improvement, we are still plagued by the crackle of static. Many attempts have been made to overcome this noisy nuisance, with some degree of success. It remained for Edwin H. Armstrong to develop a practical circuit which eliminates static. His frequency-modulation (f-m) circuit also makes possible the reception of higher fidelity music than was practical with the older amplitude-modulation (a-m) system.

You will study in this chapter the differences between frequency-modulation and amplitude-modulation receivers and transmitters, as well as something about the technical operation of this new type of circuit.

In this chapter you will learn the following things:

Part 1: What Frequency Modulation Is
Part 2: How Frequency Modulation Compares with Amplitude Modulation
Part 3: How the Basic Frequency-modulation Circuit Differs from the Basic Amplitude-modulation Circuit

PART 1: WHAT FREQUENCY MODULATION IS

You have read a great deal about frequency modulation (f-m) in the news and in popular technical magazines, and you may have wondered what the name meant. You studied amplitude-modulation (a-m) in Chapter 22. You learned in that chapter that in amplitude-modulation broadcasting, the sound waves set up voltages in the speech amplifier and modulator circuit which

varied the *strength*, or *amplitude*, of the radio-frequency carrier wave.

In frequency modulation the strength of the carrier wave remains the same at all times. Modulation changes the *frequency* of the carrier in this system of broadcasting.

PART 2: HOW FREQUENCY MODULATION COMPARES WITH AMPLITUDE MODULATION

The new frequency modulation system has a number of advantages over the standard type of amplitude-modulation broadcasting. The outstanding advantages are the unusual sound-volume range, the high fidelity of reproduced music, and the elimination of static. Listen to a standard broadcast, and notice that you hear few very faint sounds and few extremely loud sounds. In the broadcast station an operator sits before a control panel where meters show him the volume of the sound picked up by the studio microphone. A part of his job is to keep the sound level uniform. He must be particularly careful that no extremely loud sounds get through, because they overload the transmitter. But when you listen to a frequency-modulation receiver, you will be able to hear the whisper of wind or the roar of a train crossing a trestle.

Another advantage is the ability of the frequency-modulation radio system to broadcast sounds ranging from the lowest frequencies to the highest that the human ear can hear. The amplitude-modulation system covers from about 60 to 5000 cycles, and the frequency-modulation system covers from 30 to over 15,000 cycles. In frequency modulation you will hear the wide sound range of the pipe organ. You will hear the high frequencies which give brilliance and life to the speaking voice, to a singer, particularly a soprano, and you will hear the upper reaches of the violin, the piccolo, and similar instruments. You now should be able to hear the hiss of escaping steam and the true shriek of a tire. Your ear may have to be reeducated to the realism of the new frequency-modulation system.

The same higher fidelity can be built into the amplitude-modulation system, but several serious technical problems immediately arise. First, the amplitude-modulation high-fidelity system would be considerably more expensive than the present system. Second, a wider band of frequencies would be needed for each amplitude-

Electronics

TESTING CONDENSERS IN ENVIRONMENTAL CHAMBER

Condensers must be severely tested for reliability. Not only are they used in equipment operating in regions of intense cold, but they are also used in guidance and control circuits of missiles, where intense heating occurs.

modulation broadcast station. At present, each amplitude-modulation station is allowed a space of 10 kilocycles in the frequency spectrum. This limits the amplitude-modulation system to a 5000-cycle audio tone (5000 cycles on each side of the station frequency). This limitation is due to the frequency allocations

made by the Federal Communications Commission and is *not* due to equipment limitations. High-fidelity amplitude-modulation systems would reduce the number of broadcast stations now on the air, because each station would require a wider slice of the frequency spectrum (about 30,000 cycles instead of 10,000 cycles, as at present, to equal the fidelity of the frequency-modulation system). This would be extremely difficult, because the demand is for more rather than for less broadcast stations.

There are several reasons why the frequency modulation station can be designed and built to broadcast the wider range of audio frequencies. One reason is that the frequency modulation stations are now assigned a band of frequencies ranging from 88,000 to 108,000 kilocycles. (A simpler way to write these frequencies is 88 to 108 megacycles. *Megacycle* means 1000 kilocycles.) This is a frequency band 20 megacycles wide. This means that many more frequency-modulation stations can operate on the new frequency-modulation band than in the broadcast band, which is a little more than 1000 kilocycles, or 1 megacycle, wide.

Another reason is that the frequency-modulation transmitter, because it operates on very high frequency, has the relatively short range of about 50 miles. This is the line-of-sight distance you have read so much about. The frequency-modulation antenna mounted on top of a tower several hundred feet high will be in sight of the receiving antenna. Stations over the horizon from the frequency-modulation antenna will receive poorly if at all, reliable transmission being confined to the 40-mile radius. Occasionally, longer distances are reported, owing to skip, but these ranges cannot be depended on for reliable, good reception.

What about static? The elimination of static, which has been called the chief reason for the development of the frequency-modulation system, stems from the basic principle on which frequency modulation operates. You may recall that sound entering the microphone of the standard amplitude-modulation transmitter produces changes in the amplitude of the carrier wave in the antenna. You will learn as you study this chapter that changes of amplitude are completely eliminated in both the frequency-modulation receiver and the frequency-modulation transmitter. This feature in the receiver and transmitter is responsible for static-free reception.

What is your new frequency-modulation receiver like? Your new receiver probably has two radios in one, a combination amplitude-modulation and frequency-modulation set. Most communities have one or more frequency-modulation broadcasting stations. Receivers within a 50-mile radius of this frequency-modulation transmitter are able to receive its fine, high-quality music and programs on the frequency modulation part of the set. But if you wish to receive a short-wave program direct from some other country, you switch to the amplitude modulation section of your receiver where you still have the problem of fading and static, which now are a curse to much long-distance reception.

The better frequency-modulation sets have a high-fidelity speaker and a fine audio amplifier which bring you music of unusual tone range and great realism. The high-fidelity speaker has a "woofer" for the bass tones and a "tweeter" for the high tones. A special filter circuit between the output transformer and the voice coils separates and directs the low frequencies to the woofer and the high frequencies to the tweeter. In the high-fidelity speaker of the future, this job will no doubt be combined in one complete operation.

You tune the frequency-modulation receiver just as you tune your amplitude-modulation set. Its dial is marked with a new set of frequencies starting at 88 megacycles and running to 108 megacycles, or by numbered channels (each channel is 200 kilocycles wide), while your amplitude-modulation receiver is marked from 550 to 1750 kilocycles. The new set also has volume and tone control.

Questions

1. List the advantages claimed for frequency modulation.
2. List the disadvantages of frequency modulation.
3. List the advantages of amplitude modulation over frequency modulation.
4. What frequencies are used for frequency modulation?

PART 3: HOW THE BASIC FREQUENCY-MODULATION CIRCUIT DIFFERS FROM THE AMPLITUDE-MODULATION CIRCUIT

Examine the basic amplitude-modulation transmitter. First examine the amplitude-modulation transmitter, since you have already studied this circuit. The block diagram in Fig. 515 shows an oscillator which sets up a steady radio-frequency carrier. Its

output is fed to one or more radio-frequency amplifiers which increase the amplitude of the radio-frequency carrier. The output of the final radio-frequency power amplifier is connected to the antenna. This part of the amplitude-modulation transmitter generates powerful radio-frequency carrier waves. Connected into this system is a modulator.

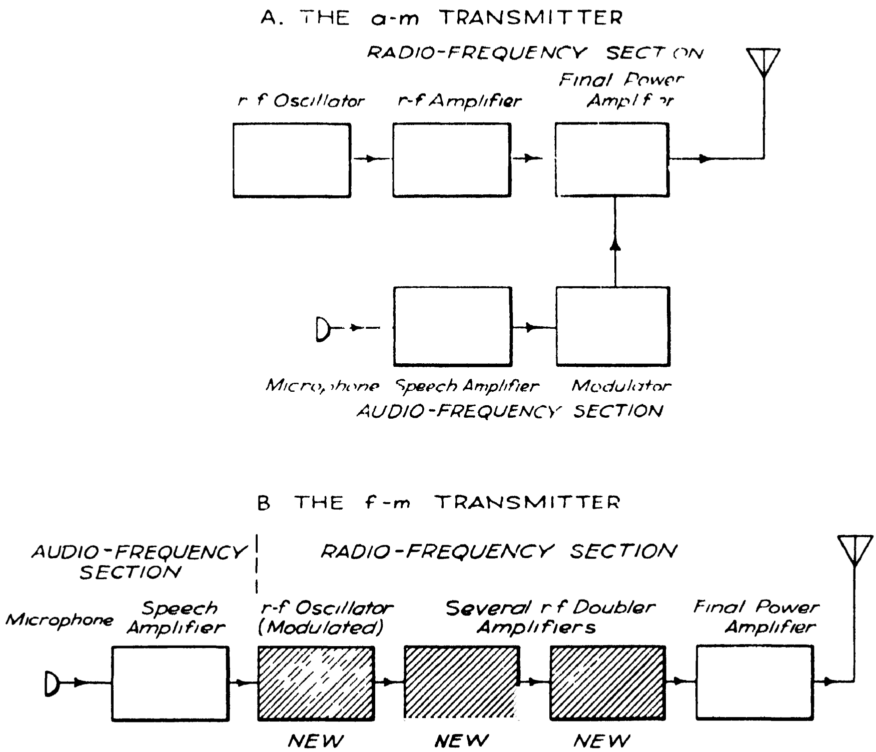


Fig. 515. Use these block diagrams to compare the amplitude-modulated (a-m) and the frequency-modulated (f-m) transmitters. Note the new circuits in the f-m transmitter.

The microphone converts the energy in sound waves into currents of varying strength. These currents are amplified in the speech amplifier and are fed to the modulator circuit, which controls the amplitude of the radio-frequency output of the transmitter so that the modulated carrier wave corresponds to the sounds coming into the microphone. This carrier wave in the antenna sends a wave through space to your receiver.

Note carefully that the amplitude-modulation transmitter produces a radio-frequency carrier wave which has *no change in frequency but which has a constantly changing amplitude* that follows the amplitude of the sound waves entering the microphone.

Examine the frequency-modulation transmitter. Now contrast the block diagram of the frequency-modulation transmitter in Fig. 515 with the one you have just studied. Here you find the microphone, the speech amplifier, and the modulator doing exactly the same job as in the amplitude-modulation transmitter. But when the output of the modulator reaches the radio-frequency oscillator, a new phenomenon occurs. The oscillator in the amplitude-modulation transmitter produced a carrier wave with steady amplitude at a fixed frequency. But here the modulator changes the output frequency of the radio-frequency oscillator. These frequency changes follow the sound entering the microphone.

The modulated output of the oscillator is now fed into several radio-frequency doublers, where the radio frequency of the oscillator is quadrupled. This is done for several reasons, one of which is to produce a final output frequency in the antenna somewhere in the new frequency range assigned to the frequency-modulation transmitter. It also allows a low frequency to be used in the radio-frequency oscillator. It is not necessary to vary the frequency of the oscillator over too great a range, because each doubler circuit will double the frequency swing, and enough doublers or quadruplers may be added to give the required frequency swing in the output circuit.

Two new results occur when the speech currents from the modulator reach the radio-frequency oscillator in the frequency-modulation transmitter: (1) the loudness of the sounds controls the radio-frequency swings away from the fixed oscillator frequency (this is called *frequency deviation*); (2) the pitch of the sound at the microphone controls the rate at which the frequency deviation occurs.

Compare the frequency-modulation and the amplitude-modulation receivers. Examine the block diagrams in Fig. 516. Both receivers, you will note, use the superheterodyne principle. Both have a radio-frequency mixer, a high-frequency oscillator, and a radio-frequency amplifier. But the frequency-modulation receiver uses a broadly tuned radio-frequency amplifier, while the radio-

frequency amplifier in the amplitude-modulation system is sharply tuned. The wide-band amplifier is needed because of the wide frequency band (200 kilocycles) used by the frequency-modulation system. The narrow-band intermediate-frequency amplifier is possible in the amplitude-modulation system because it uses a frequency band of only 10 kilocycles.

The *limiters* shown in the next two blocks are new circuits. They are low-gain amplifiers whose purpose is to prevent any change in the amplitude of the received signal, such as surges caused by static or other interfering signals.

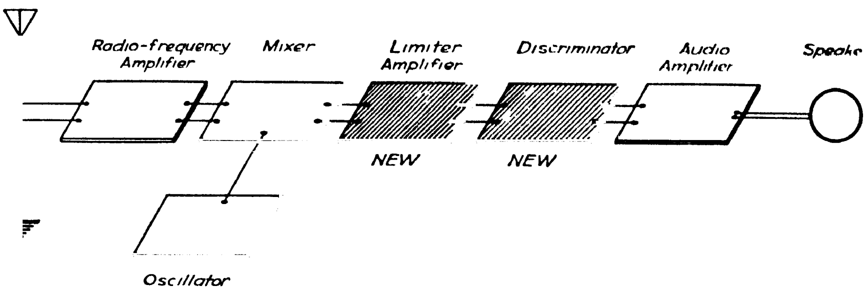


FIG. 516. Here are the different unit circuits of the frequency-modulated receiver. Note that there are two new units, the *limiter* and the *discriminator*, or *detector*.

The second detector in the amplitude-modulation system is replaced in the frequency-modulation circuit by a specialized detector called a *discriminator*. The discriminator's job is to convert radio-frequency deviations produced by the audio modulator at the transmitter back to audio currents in the receiver's output circuit which can be amplified and fed to the speakers. This will then produce high-fidelity sound.

Now let us go on to a more detailed study of the frequency-modulation transmitter and see how it produces these frequency variations. A complete and detailed explanation of this system is beyond the scope of this text, but the explanation given here will give you a general understanding on which to build a later technical study of this rather complex procedure.

A description of a simple demonstration transmitter may help to explain further the difference between a frequency-modulated wave and an amplitude-modulated wave. You can couple a condenser microphone to the Hartley oscillator and have a simple

frequency-modulated transmitter which will illustrate the frequency-modulated-transmitter principle. This is done by connecting the microphone in parallel across the plate tank coil or condenser (see Fig. 517).

How a Simple Frequency-modulated Transmitter Works

The Hartley oscillator sets up a radio-frequency oscillation of steady frequency and of uniform amplitude.

Action of the Microphone. When you speak into the microphone, your voice sets up sound waves that consist of compressed regions and rarefied regions of air pressure which move the microphone diaphragm. A compressed region moves the diaphragm

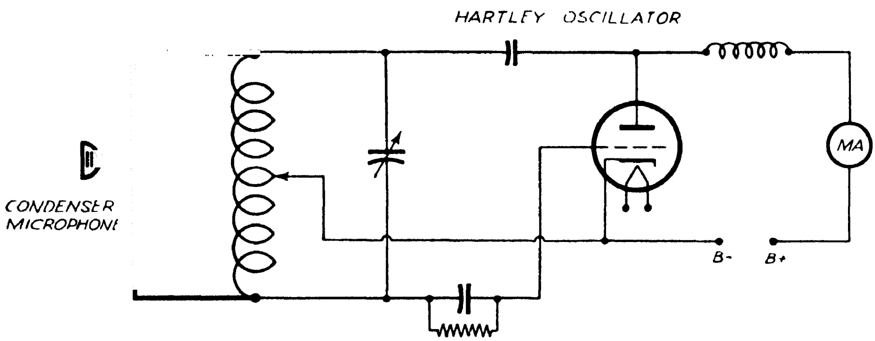


FIG. 517. Connect a condenser microphone to an oscillator circuit and you have a simple frequency-modulated oscillator.

inward. The rarefied region moves the diaphragm outward. As the diaphragm moves, the capacity of the condenser microphone changes. When the diaphragm moves inward and the space between the plates becomes less, the capacity of the microphone increases; when the motion of the diaphragm is outward, the capacity decreases.

Effect on the Radio-frequency Wave. The tiny motions of the diaphragm of the condenser microphone affect the frequency of the tank circuit just as if the tuning condenser rotor were turned.

When the condenser capacity increases, the frequency of the tank circuit is lowered. When the condenser capacity decreases, the frequency is raised.

Therefore, when you speak into the microphone, the different rates of vibration of your voice cause corresponding changes in the

frequency of the radio-frequency wave set up in the oscillator. This is frequency modulation.

The amplitude, or strength, of the radio-frequency waves remains the same.

How a Loud Sound Affects Modulation. When you speak loudly, the compressed and rarefied waves are more intense, and they cause the diaphragm to move a greater distance than does a soft sound. The increased motion of the diaphragm causes the frequency of the oscillator to increase and decrease more than when a soft sound enters the microphone. Loudness affects the timing, or frequency, and not the amplitude, or strength, of the radio-frequency waves as in amplitude modulation.

The actual modulator circuits used in practice are much more complicated than the one shown here.

Questions

1. Compare the carrier waves for amplitude modulation and frequency modulation under the following conditions:

   a. A loud sound
   b. A soft sound
   c. A high-pitched sound
   d. A low-pitched sound

2. Explain why static does not affect the reception of frequency modulation.
3. Why is frequency modulation not released over the regular broadcast bands?
4. Make a list of ways in which the frequency modulation sets differ in construction from amplitude modulation sets.
5. Make a list of circuits and parts which are found in both amplitude-modulation and frequency-modulation sets.

The limiter circuit. An important feature of the frequency-modulation receiver is the no-static part of the circuit. Especially in the city, where there are many causes of interference, does this feature offer a great improvement over the amplitude-modulation receivers. You can listen to your favorite morning news broadcast without having the annoying growls of the neighbor's electric razor or the hum of a mixer stirring waffles interfere with the news.

Sign flashers, motor-commutation noise, ignition noise from passing cars, the pop when a switch is thrown—all of these annoyances and the crackle and roar of atmospheric static are eliminated by the limiter circuit. A limiter may be likened to a dam which holds back sudden increases of water from storms. The flow of

water from the dam can be controlled, and its outflow can be regulated to any desired amount.

The limiter circuit, shown in Fig. 518, is a form of radio-frequency amplifier. It takes the place of the intermediate-frequency amplifier in the standard amplitude-modulation superheterodyne circuit. The new features of the limiter circuit are its low plate voltage and the grid-condenser grid-leak bias which allows the tube to saturate so that voltage peaks on the grid make no corresponding peaks in the plate current.

You may recall that the output of the frequency-modulated transmitter was of uniform amplitude. The sudden peaks in the received wave caused by static and atmospherics would normally pass through the circuits of the frequency-modulation receiver if

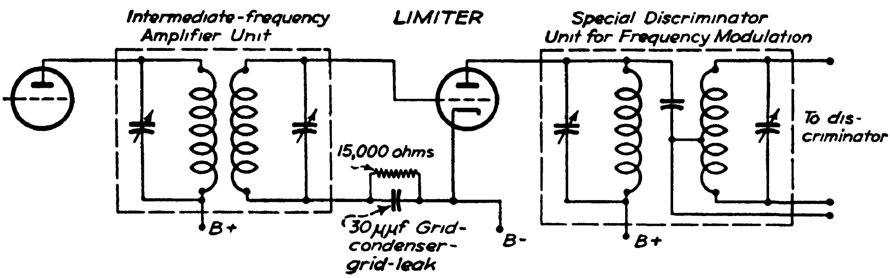


FIG. 518. This is a circuit of the limiter that removes the noise and static surges from the modulated carrier wave.

these peaks were not leveled in the two limiter circuits of the frequency-modulation receiver.

How the limiter operates. Since the plate voltage is low (about 75 volts) the tube will easily saturate when a strong signal is on the grid.

The bias on the grid is obtained from the grid condenser and grid leak. If the signal from the station being heard is strong enough to saturate the limiter, it increases the voltage on the grid to a point where the tube has its greatest amplification. (The gain of a tube is limited, that is, the amplification is greatest at a certain predetermined grid-plate voltage.) But the grid-bias voltage of the limiter varies with the strength of the signal being received, so that a strong signal automatically levels itself in the output of a limiter down to the strength of a weaker signal. Bursts of static are also limited down to the volume of the signal

being received. Your ear cannot detect them in the radio program because of their short duration. If the signal is too weak to saturate the limiter, static will be heard.

Two limiters are needed to give perfect limiting. As a rule, a tube is selected for the second limiter which requires that a higher voltage be developed on its grid before it reaches its highest amplification point.

The purpose of the discriminator. The limiter delivers a radio frequency of uniform amplitude to the discriminator. But the frequency is varying, or changing, at the rate of the sound waves that produce the frequency modulation in the frequency-modulation transmitter. (The frequency deviation.) The discriminator

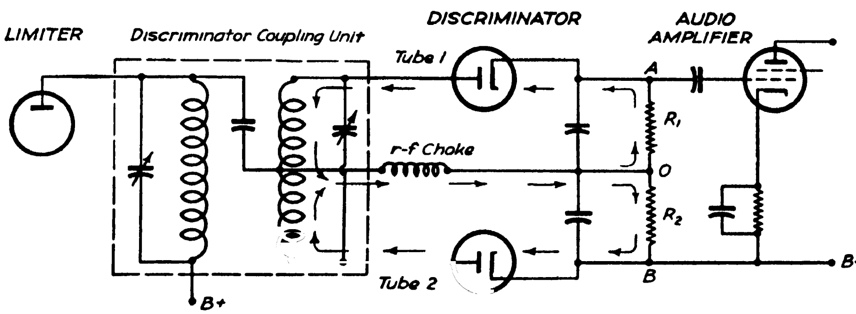


FIG. 519. This is the discriminator circuit. This circuit does the same job in the frequency-modulated receiver that the detector does in the amplitude-modulated receiver.

must use these frequency variations in some way to get alternating voltages which can be applied to the audio amplifier so that sounds will be produced by the loudspeaker. Note that the discriminator, which is the second detector of the frequency-modulation superheterodyne receiver, operates on quite a different principle from that used by a standard amplitude-modulation superheterodyne receiver. Where the ordinary receiver deals with changes in amplitude, the frequency-modulation receiver operates on changes in frequency.

Description of the discriminator circuit. At first glance, the new circuit shown in Fig. 519 looks like the full-wave rectifier circuit which you studied in Chapter 14, "Power Supplies." Like the power supply, the discriminator uses a transformer which supplies power to the circuit. It has two rectifier tubes (either a

double diode or two diodes in one envelope). It also has the center tap to the transformer secondary.

However, this circuit has several new features. The input transformer is especially designed for the frequency-modulation circuit. Both primary and secondary are tuned with trimmer condensers. Both coils are closely coupled and are designed to tune over a wide band of frequencies instead of tuning sharply to a narrow band, as in the standard amplitude-modulation intermediate-frequency transformers. Note also the addition of a coupling condenser from the plate end of the primary to the center tap of the secondary.

There is a load resistor connected to the cathode of each diode tube, and there is a by-pass condenser across each resistor. The output of the discriminator is taken off at the ends of the two resistors marked *A* and *B*.

How the discriminator is lined up. The discriminator is lined up while receiving an unmodulated wave. The intermediate-frequency trimmer condensers are tuned so that a meter attached across points *A* and *B* on the output resistors will indicate zero. The radio-frequency carrier, which reaches the tuned discriminator circuit, both by induction and by capacity, sets up electron surges in the tuned secondary circuit. These surges make the plate of tube 1 positive, and one-half cycle later make the plate of tube 2 positive. This causes electrons to flow through each tube as shown by the arrows in Fig. 519.

The electrons flowing through tube 1 for one-half cycle flow through R_1 from *O* toward *A* and on through the tube. During the next half cycle, the electrons flow from *O* toward *B* and on through tube 2. Point *O* is negative because electrons are flowing to *O* through the return wire. Points *A* and *B* are positive because the electrons are pulled from *A* and *B* by the electronic surges in the tuned circuit.

No sound will be heard from the loudspeaker, because the voltages between points *AO* and *BO* are equal and opposite and make no voltage changes on the grid of the audio-amplifier tube.

How sound is produced by the action of the discriminator. Sound will be heard from the loudspeaker only when the voltage on the grid of the audio-amplifier tube is changing in strength. To get voltage changes across the two load resistors R_1 and R_2, it is necessary that more electrons flow through one or the other

of the two tubes. This will force electrons on or off the amplifier-tube grid, and sound will be produced.

How frequency changes produce unbalanced voltages a mechanical analogy. The combined electrical effect of the coupling condenser and the discriminator transformer is similar to the action of a center-tap connection if you could move it from one

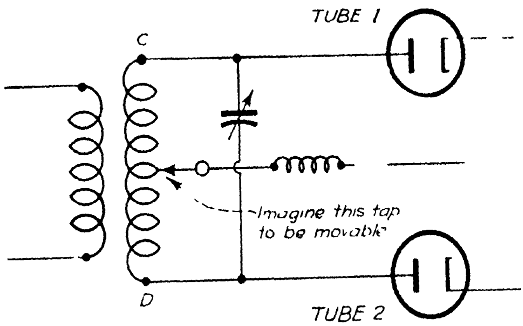


FIG. 520. Study this imaginary circuit to understand the action of the discriminator. *Imagine* the tap to be movable with the frequency deviation.

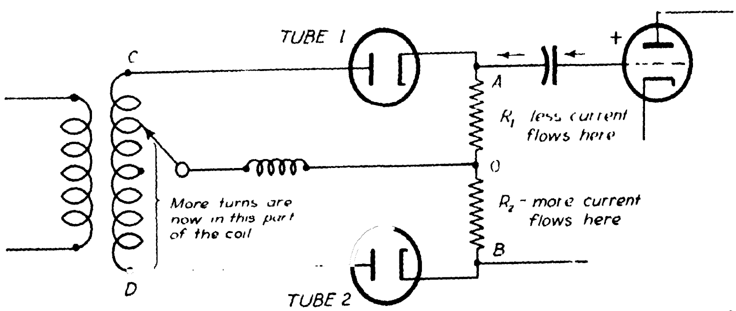


FIG. 521. As the center tap "moves" toward C, more current will flow through tube 2 and through resistor R_2.

side of the center of the coupling coil to the other (see Fig. 520). With the moving tap at the center of the coil at O, the electronic flow through each tube would be equal, and the same voltage would be set up in each half of the coil during each half cycle if the radio frequency were kept constant.

But when you moved the tap toward C, as in Fig. 521, there would be a greater voltage through the part of the coil on side D, which would now include more turns. This would produce a greater electronic flow through tube 2 and through resistor 2.

The voltage drop across R_1 and R_2 would now be unbalanced and would pull electrons off the grid of the audio-amplifier tube.

However, when you moved the center tap toward D (see Fig. 522) conditions would change and the electronic flow would be greater through tube 1. More electrons would now flow through R_1, and electrons would be pushed onto the grid of the audio tube. The changing voltage on its grid would produce sounds in the loudspeaker.

If you could move the center tap at the proper rate, you could hear corresponding sounds from the speaker, because the differences in voltage across R_1 and R_2 would occur at the same rate

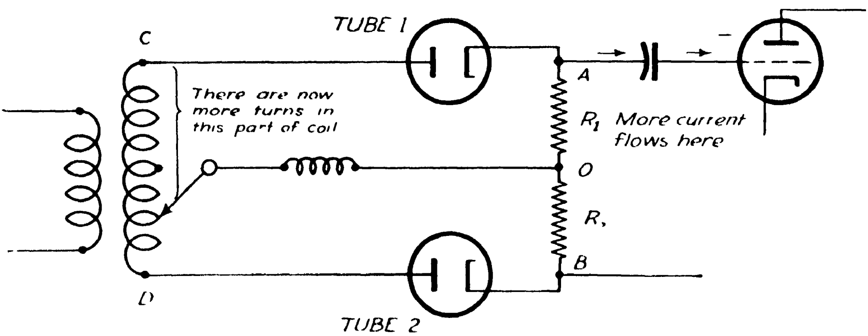


FIG. 522. More current now flows through resistor R_1.

as the sound entering the microphone at the transmitter. But it would be impossible for you to move a center tap at such a high rate of speed (at radio frequency) by any mechanical device. The same effect is accomplished in this circuit electronically.

While this analogy is not exactly what takes place, it is used here to bring out the thought of different potentials being developed across a discriminator transformer as though the center tap actually moved.

These results can be obtained electrically by the coupling unit of the discriminator, which follows closely in its action the explanation you have just studied and accomplishes the same result. Its action is based on the leading effect of a condenser and the lagging effect of a coil, which are already familiar to you, to produce an action similar to that which you have just studied. The effect of the coil and of the condenser as they swing in and out of phase is the same as a sliding center tap on the coil.

Questions

1. Explain how the limiter prevents static.
2. Why are the coils in the intermediate-frequency transformers not designed to tune sharply?

Technical Terms

a-m—Amplitude modulation.

discriminator—The second detector in the frequency-modulation receiver.

f-m—Frequency modulation.

limiter—A circuit which acts to limit or eliminate the voltage surges which cause staticlike sounds in the receiver.

CHAPTER 26

DIODES AND TRANSISTORS

What Are Diodes and Transistors?

The point-contact diode and the transistor are two late developments in electronics that have come about as the result of research into the new field of solid-state physics. Solid-state physics has to do with the study of solid materials.

The discovery of the principles on which the transistor depends for its operation was made in 1948 by three scientists employed by the Bell Telephone Laboratories. They were Dr. Walter H. Brattain, Dr. John Bardeen, and Dr. William Shockley. These men were awarded the Nobel prize in physics for their discovery.

When you examine a point-contact diode, you will find that it is a tiny glass tube with two connection pigtails. The transistor is a capsule-like container with three connection wires. Any radio supply house will show you many different forms of both diodes and transistors.

Actually the diode is nothing but a tiny slab of germanium or of silicon with two connections to it. The transistor is a tiny bar or slab of germanium with three connections to it.

Both germanium and silicon have long been known to chemists and to metallurgists. The unusual electronic advantages of germanium and of silicon were discovered through a study of their crystalline and their atomic structures. Methods were also discovered by which both germanium and silicon could be supplied in nearly 100 per cent pure state. The point-contact diode and the transistor were developed as a result of these discoveries.

How Are Diodes and Transistors Made?

The point-contact crystal diode is a tiny square of germanium or silicon against which contact is made by the sharpened point of an S-shaped spring. The spring wire is a few thousandths of

an inch in diameter. The germanium and spring contact are sealed into a tiny glass enclosure about $\frac{1}{8}$ inch in diameter and about $\frac{3}{16}$ inch long (see Fig. 523).

Transistors are somewhat larger, possibly $\frac{1}{4}$ inch long. One type has a tiny germanium bar to which is welded two support wires (see Fig. 524). A third wire is welded to the center of the bar. The support wires are brought through the base as are tube pins to make contact with the circuit or with a tiny socket. A cover seals the unit.

The very small size and the light weight are two important advantages of both the diode and the transistor.

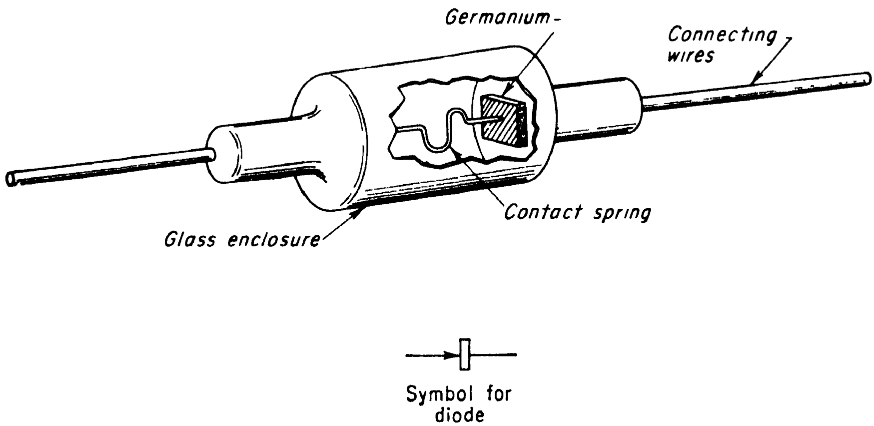


FIG. 523. The construction of one type of diode.

How Are Diodes and Transistors Used?

Diodes and transistors may, in many cases, be substituted for two- and three-element vacuum tubes in radio and electronic circuits. They are used in receiving circuits where small size is important, as in portable equipment, in vest-pocket receivers, and in paging systems. They may be used in low-power oscillators. They are used in test instruments where a small, compact rectifier is needed, as in rectifier voltmeters. Silicon diodes, which operate at much higher temperatures than germanium diodes, are used in power supplies, thus permitting great reduction in size and weight.

Guidance and firing mechanisms in rockets, missiles, and other air-borne equipment make extensive use of transistors and diodes.

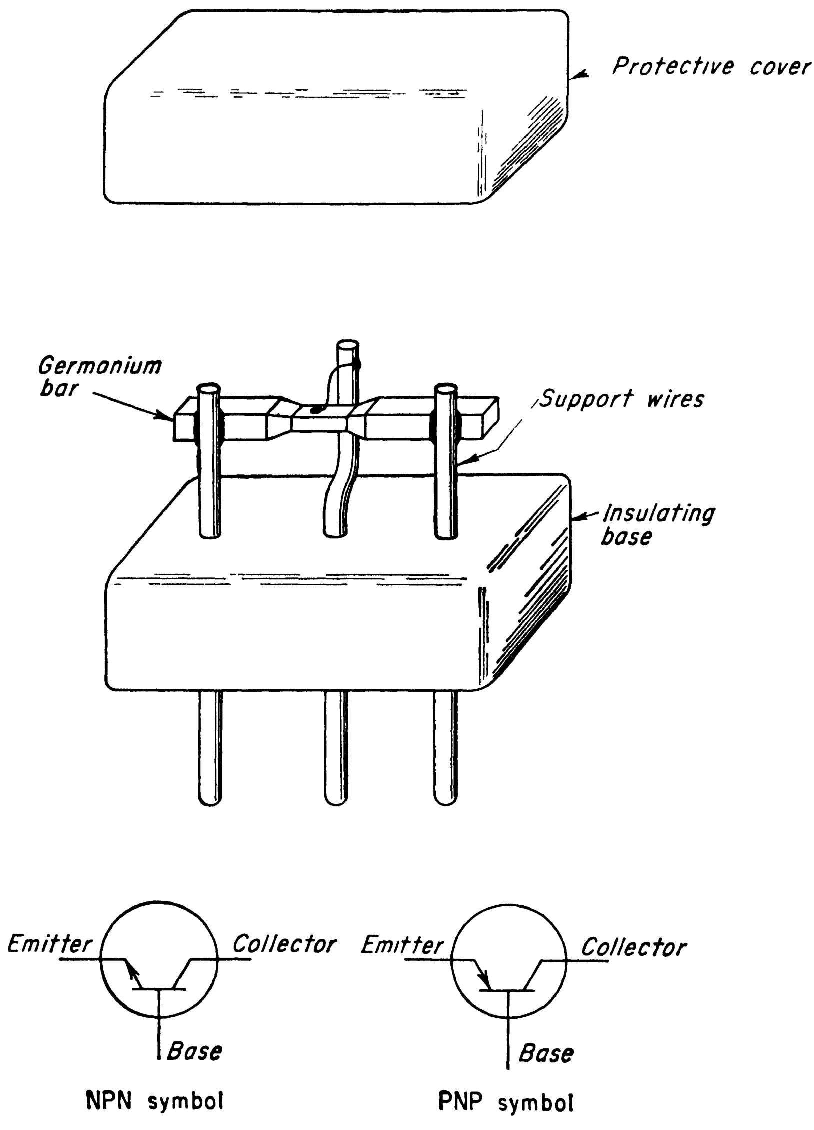


FIG. 524. The construction of one type of transistor. Note the symbols for the PNP and for the NPN types of transistors.

Bombers and interceptors carry literally tons of radio and radar equipment for use in fire control, search, and communication. They also use electronic navigational equipment, radar altimeters, auto pilots, and so on. The weight of this electronic equipment is reduced from tons to a few hundred pounds by using transistors and diodes. The fact that neither the diode nor the transistor

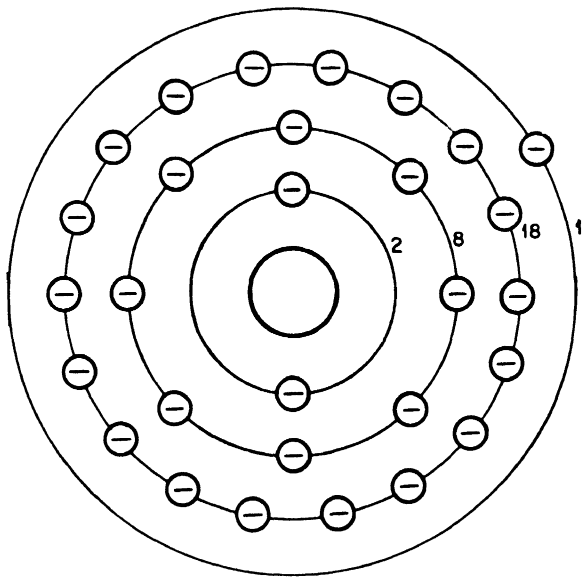


Fig. 525. The arrangement of electrons in the different rings of a copper atom (2–8–18–1).

has a filament eliminates the need for heavy filament transformers and high-voltage power supplies. The transistor operates on low voltages.

Electronic computers used in research often contained thousands of vacuum tubes. The heat from the filaments required air conditioning to keep temperatures under control in the room where a unit was installed. By using transistors and diodes, much of this expensive air-conditioning equipment has been eliminated because neither transistor nor diode produces heat in its operation unless sizable amounts of power are used.

Diodes—Why They Work

While both germanium and silicon are used in diodes, we shall use germanium to explain their operation. Let us start by examining the nature of the semiconductor, germanium. A chemist will tell you that germanium has characteristics of both metals and nonmetals. But what are metals and nonmetals as the chemist sees them?

What Are Metals and Nonmetals?

A metal is generally a conductor of electricity. Its outer ring or energy level is *less than half filled* with electrons (see Fig. 525.) It is a donor or lender of electrons because metals have electrons available in their outer ring that are loosely held to the nucleus. For this reason they are known as *conductors*. Some examples of metals that are good conductors are silver, copper, and aluminum.

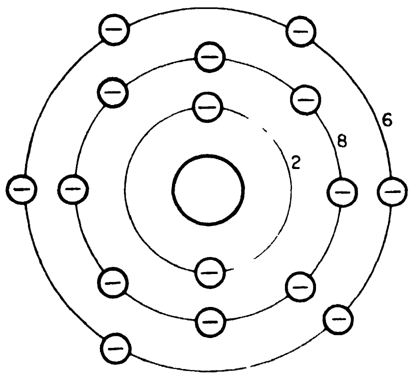


Fig. 526. The arrangement of electrons in the different rings of a sulfur atom (2-8-6).

A nonmetal is generally a poor conductor or an insulator. Its outer ring is *more than half filled* with electrons (see Fig. 526). The electrons in the outer ring are tightly bound to the nucleus. The nonmetal is an acceptor or borrower of electrons. Thus it is a poor conductor. Some examples of nonmetals are sulfur, chlorine, and iodine.

What Are Semiconductors?

The element germanium, halfway between the metals and the nonmetals, has its outer ring of electrons *exactly half filled* (see Fig. 527). Under proper conditions it can be made to behave like a metal. Under other conditions it behaves like a nonmetal. This means that germanium can be made to borrow electrons or it can be made to lend electrons. In each case it is a rather poor conductor of electricity, so it is known as a *semiconductor*.

Lending and Borrowing Electrons

Traces of other materials, added to germanium while in a melted state, can create desirable electronic characteristics in the germanium. When doped with traces of arsenic or of antimony, the germanium acts like a metal. It becomes an electron lender and is called *N type*.

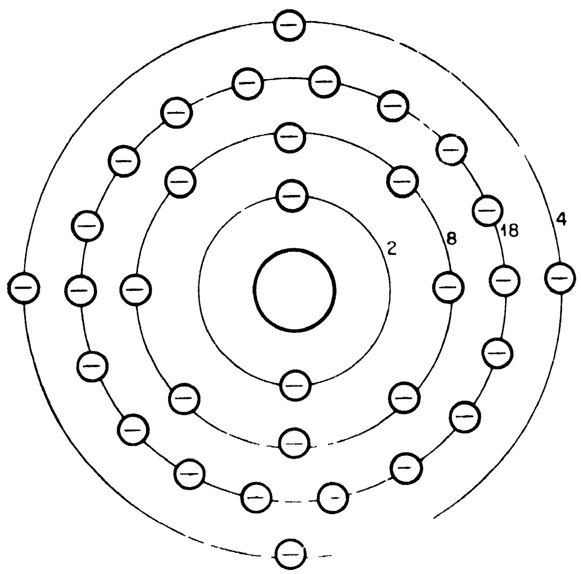


FIG. 527. The arrangement of electrons in the different rings of a semiconductor germanium atom (2–8 18 4).

When traces of gallium or of indium are used to dope the germanium melt, the germanium takes on the characteristics of a nonmetal. The germanium now becomes an electron borrower and is called *P type*.

Valence the Bond between Atoms

Although science has no pictorial answer to the question of valence, yet an accepted theory describes valence electrons as one of the "atomic glues" that hold atoms of any given material in their fixed position in the material. The word *valence* is the term used

by chemists and physicists to describe the electron pairs that hold together or join neighboring atoms.

Under normal conditions, each germanium atom shares two valence electrons with each neighboring atom (see Fig. 528). Each atom has four sharing or valence electrons. When one sharing electron of an atom joins with the sharing electron from each of its neighbors, the resulting eight sharing electrons bind any single atom tightly to its neighbors. This arrangement satisfies the normal conditions for a germanium atom (see Fig. 528).

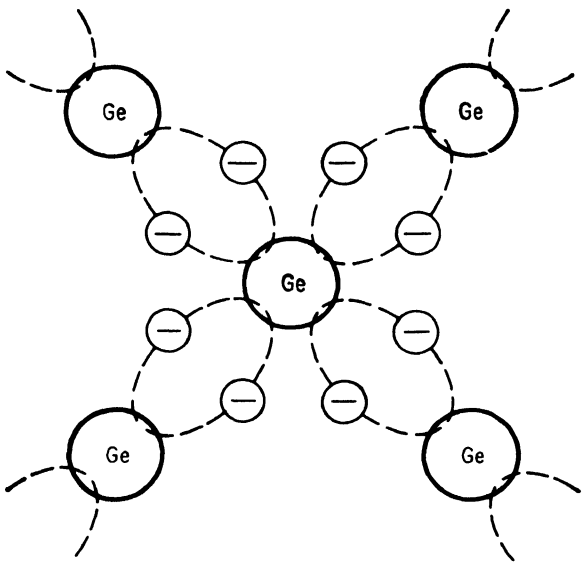


FIG. 528. This shows the valence electrons that hold the germanium atoms together. Note that each atom has four valence electrons.

To produce the type of germanium needed for electronic use, the normal condition of the atoms must be arranged so that the material becomes either an electron lender or a borrower. This is done by the doping process.

What Are Electrons and Holes?

When you read articles about transistors and other semiconductors, you will find many references to "electrons and holes." What are electrons and what are holes and how do they fit into our

explanation? Both can be explained by describing the process of doping or adding traces of impurities to the highly purified germanium to produce either the P-type or the N-type semiconductor.

Suppose that an atom of arsenic is added to the melted germanium. The arsenic atom has five sharing electrons. Four of these sharing electrons reach out and join with one electron from

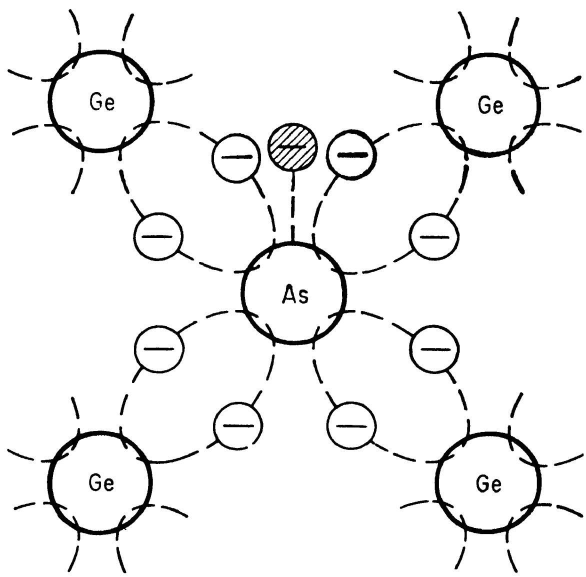


FIG. 529. When traces of arsenic (As) are added to highly purified germanium (Ge), eight valence electron bonds are formed. One electron, however, remains unjoined.

each surrounding germanium atom to form the desired group of eight sharing or valence electrons (see Fig. 529).

But one sharing electron from the arsenic atom is left unattached. There is no sharing germanium electron left with which it can join (see Fig. 529). This extra electron is held loosely enough so that it may be pushed off the arsenic atom by an external voltage to become a wandering or mobile electron. These mobile electrons form the current that drifts through the N-type germanium.

Holes are formed when the germanium melt is doped with traces of gallium or indium. Both gallium and indium have only three

electrons in their outer rings. When the three valence electrons of the gallium reach out to join with the valence electrons of surrounding germanium atoms, three pairs of electron bonds are formed (see Fig. 530).

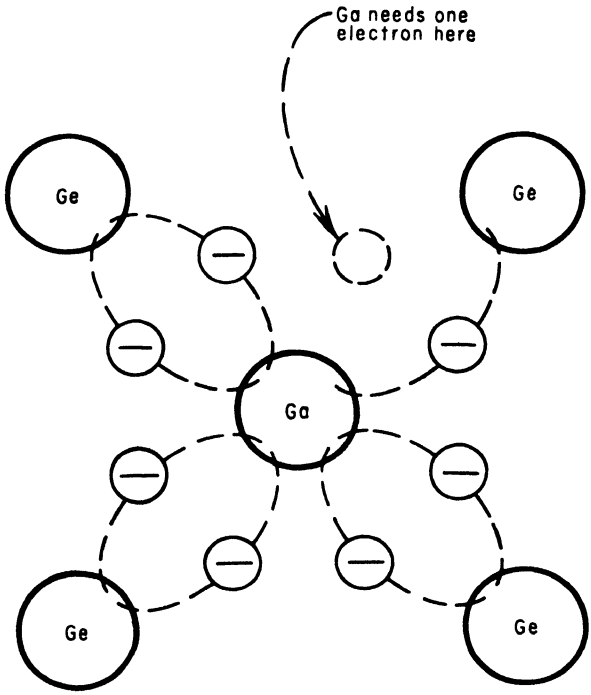


FIG. 530. When traces of gallium (Ga) are added to the germanium, it becomes P type. Here the gallium, with only three valence electrons, needs an electron to complete its valence group of eight electrons.

The gallium atom robs one valence electron from a nearby germanium atom. The gallium atom can now share the borrowed electron with another germanium atom to build up the complete set of eight valence electrons (see Fig. 531). But the germanium atom from which the electron was borrowed is short one electron. The space for the missing electron is called a *hole* (see Fig. 531). The germanium is called *P type* or *positive*. It becomes an electron borrower.

The electrons and holes are said to "travel" or to migrate through the germanium. This effect is often called *electron diffusion through the material*.

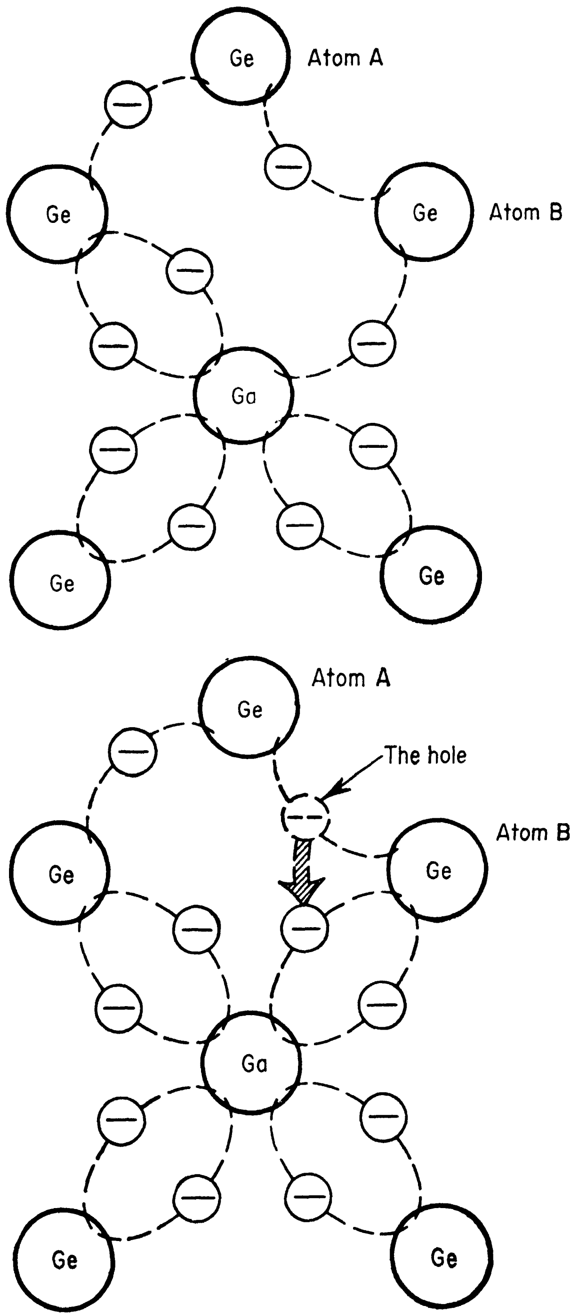


FIG. 531. Although these atoms look as if they are in a flat plane, they actually are part of a complex lattice formation. Atom *A*, from which the gallium atom borrowed an electron, is nearby in the lattice with its three remaining electrons paired with nearby atoms in the lattice.

The Operation of a Crystal Diode Rectifier

Let us now examine a piece of germanium doped so that one part is P type and the other part is N type (see Fig. 532). This forms a junction or two-element rectifier. Let us see how it acts when a battery is connected to it as in Fig. 533.

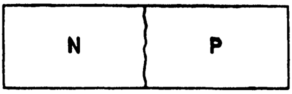


FIG. 532. Part of this germanium diode has been doped to form P-type material. The rest of the semiconductor has been doped to form N-type material.

The Atoms Become Ions

We have learned how impurities added to germanium formed either donor or acceptor material. Let us examine an atom of N-type material. When the arsenic impurity atom was added, four of its five electrons formed valence bond pairs with nearby germanium atoms. The fifth electron became a free electron, moving about among the atoms of the germanium. The arsenic atom has become a *positive ion* by losing one electron. This germanium is the N type or a donor material because of the free electron.

Likewise, when the impurity was a gallium atom with three electrons, the gallium atom robbed one electron from a nearby germanium atom to form its four valence bond pairs. The gallium atom, now with a fourth electron, has become a *negative ion* because of the fourth electron. This germanium is the P type or acceptor material.

The Junction Is an Electron Barrier

From our past study of electrons we would expect the free electrons in the N-type germanium to rush across the junction to fill the hole spaces in the P-type germanium. Electrons near the junction are repelled by the negatively charged ions in the P-type material, so no current flows across the junction. This repelling force is sometimes called a "potential hill," a repelling voltage.

The Need for an Operating Bias

While either heat or light could be used to add enough energy to force the electrons to cross the junction barrier, it is more common to use a bias battery to add the needed energy. Let us see what effect the battery has on diode operation.

How Does the Diode Operate?

In Fig. 533, a bias battery has been connected across the ends of the diode. When the voltage of the battery is higher than the repelling force of the negative ions in the P-type germanium, electrons can cross the junction and a current will flow. This is called a *forward current.*

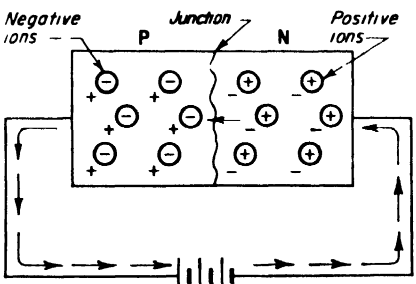


FIG. 533. When the battery voltage is great enough to overcome the repelling force of negative ions in P type material, electrons can cross junction

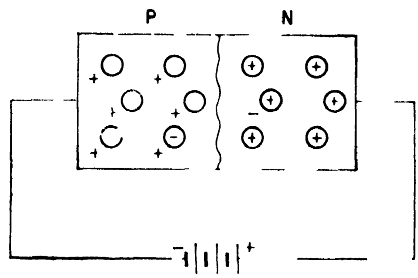


FIG. 534 Now, with the battery reversed, electrons are drawn away from the junction so that none cross and no current flows.

But when the battery is reversed, as in Fig. 534, no current will flow. The free electrons in the donor material are drawn away from the junction by the battery. With no free electrons to carry the current, no current will flow across the junction. This is the rectifying action of the germanium diode.

How Does the Transistor Operate?

While there are several ways to explain the operation of the transistor, one way that is easy to understand compares its operation to the operation of a triode vacuum tube. Because you already understand this, it is a good starting point. The fundamental differences in the operation of the two devices will be explained as we go along.

Both the transistor and the vacuum tube have three elements. In the vacuum tube these elements are the cathode that supplies the electrons; the plate that attracts and collects the electrons from the cathode; and the grid, which is placed between the cath-

ode and the plate where it can control the stream of electrons (see Fig. 535).

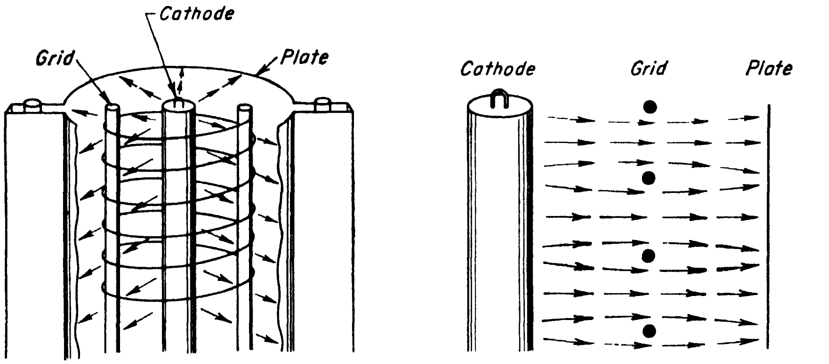


Fig. 535. The grid, placed between the cathode and the plate, can easily control the flow of electrons on their way to the plate.

The transistor also has three elements. As drawn in Fig. 536, one element is the emitter. In this case it is N-type germanium. Here it corresponds to the cathode in the vacuum tube. Then there is a very thin section of P-type germanium called the *base* that corresponds to the grid. Finally at the other end of the bar there is another section of N-type germanium called the *collector*.

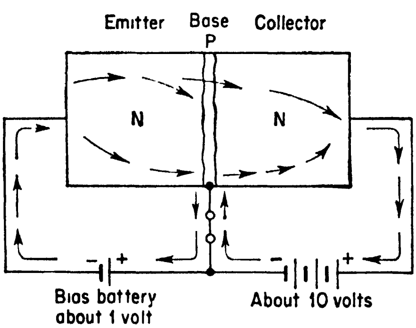


Fig. 536. This germanium has been doped to produce an N section called the *emitter*, a very thin P section called the *base*, and another N section called the *collector*.

The transistor can also be made with its ends P-type germanium and the center N-type. This type is called a PNP-type transistor. The one drawn in Fig. 536 is an NPN-type.

A fundamental circuit for this transistor, shown in Fig. 536, has a bias battery of about one volt, connected between the emitter and the base. The bias battery causes a weak but steady flow of electrons through the emitter into the P-type base region. The battery connected between the base and the collector may be about 10 volts. Little current flows in this collector circuit because it is

trying to flow in a backward direction from the P-type base to the collector.

Electron Diffusion through the Transistor

Electrons flow easily through the emitter and diffuse into the base. Since this current flow is in the forward direction, there is relatively little resistance to its flow. Because the base region is very thin, most electrons will diffuse on into the collector without being captured by the holes in the base.

How the Base Controls the Electron Drift

Suppose we connect the transistor into some circuit such as a simple receiver as shown in Fig. 537. We might bring the wires from the tuning circuit of the receiver to the points marked "x-x." The electron surges through this circuit will now drive electrons onto the base at one instant and it will pull them off the base at the next instant.

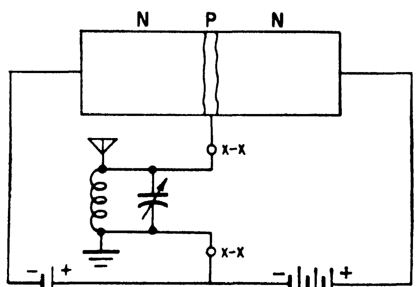


FIG. 537. Here the transistor is connected to an antenna tuner and a tuning capacitor.

When the base is thus made more positive, it will attract more electrons from the emitter. The current from the emitter to the collector will then increase because more electrons will be available to diffuse into the collector.

But when the base is made less positive, fewer electrons will flow through the transistor because the electrons on the base will repel those in the emitter. So we see how the base region acts like the grid in the vacuum tube to control the flow of electrons through the transistor.

Transistor Amplification

The effect of a very small supply of electrons on the base controlling a large flow of electrons through the emitter-to-collector circuit is called *amplification.* The base thus acts like a traffic cop, at one instant hurrying the electrons through the transistor and at the next instant reducing or stopping the flow. The traffic

cop, in this case, is acting on the directions of the outside circuit, using the electrons it supplies as his traffic baton to move or to stop the flow of electron traffic.

Transistors and Diodes in Practical Circuits

Now that you have studied the action of the diode and of the transistor, it will be interesting to try them out in several circuits.

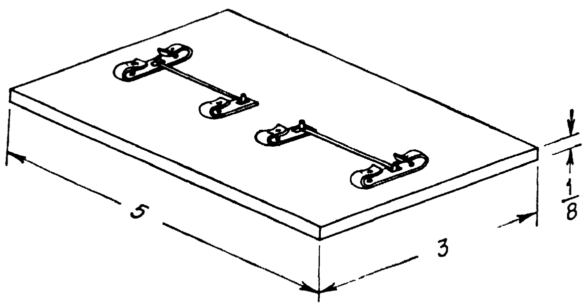


FIG. 538. Make a crystal diode board as shown in this drawing.

To give you a comparison of how they simplify circuits that you used earlier in this book, you may replace the crystal detector and the triode tube with the diode or with a transistor.

Build a Diode Circuit Board

Cut a piece of $\frac{1}{8}$-in. × 3-in. × 5-in. plastic or Masonite for the base. Drill holes for $\frac{6}{32}$-in. flathead screws as shown in Fig. 539. Attach two double Fahnestock clips and two single clips as shown. Countersink the holes on the back of the baseboard so that the flathead screws will be a little below the surface of the baseboard. Solder connecting wires as shown in Fig. 538.

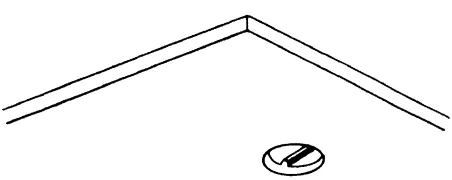


FIG. 539. Countersink the hole from the back of the base so the flathead screw head will be below the surface of the board.

How to Wire and Operate It

Connect the antenna and ground wires to the diode circuit board as shown in Figs. 540 and 541. Attach earphones to the

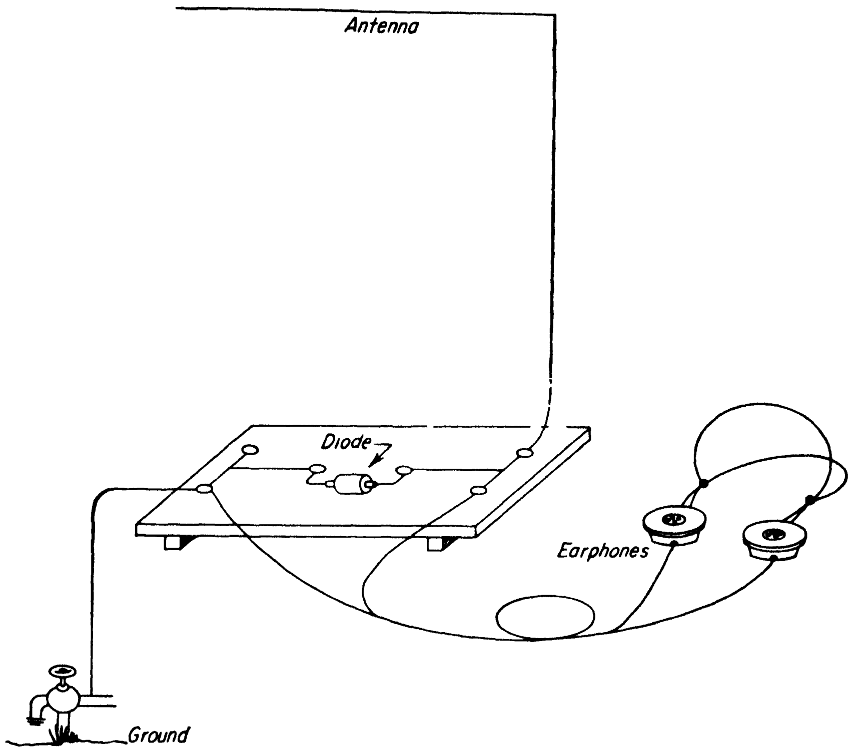


FIG. 540. Connect the antenna, ground, and earphones as shown here. Then connect the diode. Compare this hookup with that in Fig. 106.

double Fahnestock connectors. Clip the connection wires of the crystal diode to the two single Fahnestock connectors and your set is in operation. You will hear some station when you listen in the earphones.

Note the ease of operating this simple circuit. There is no difficulty in finding a sensitive spot on the crystal. This is done by the manufacturer. There is no cat whisker to jar off the sensitive position. There is no variation of volume caused by poor contact as there was with the earlier cat whisker.

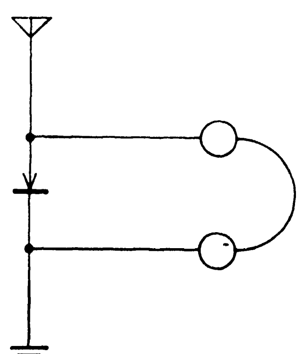


FIG. 541. Compare this schematic diagram with the diagram in Fig. 107.

Other Experiments to Try

You can add a slide tuner as in Figs. 154 and 155 or you can add an antenna coil and tuning condenser as in Figs. 156 and 157 to see how the crystal diode detector compares with the one-tube

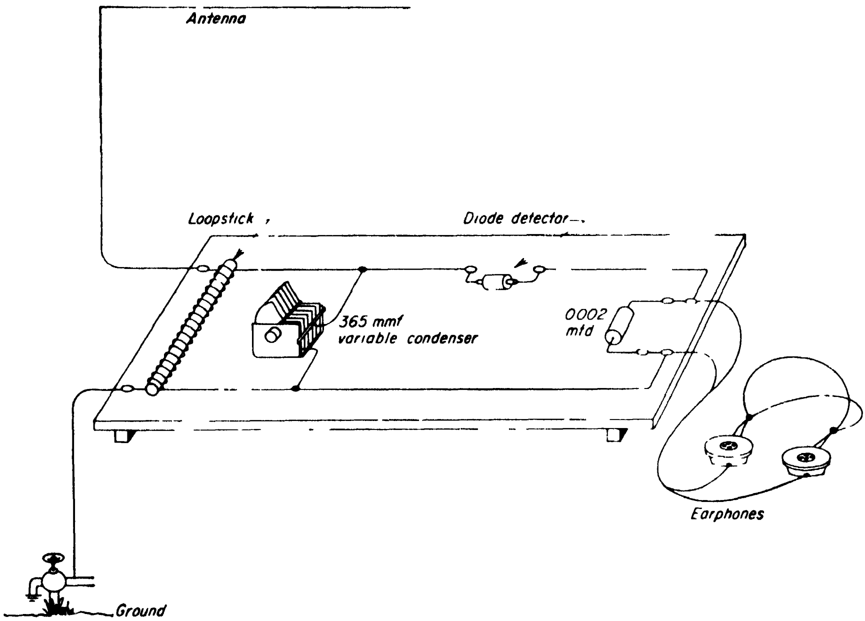


FIG. 542. The board layout for a tuned diode receiver.

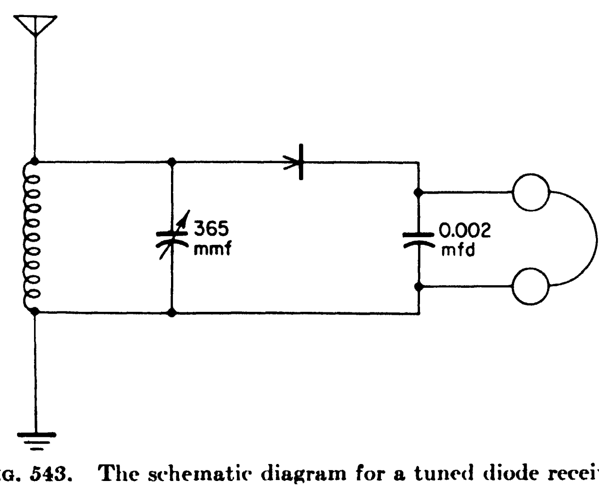


FIG. 543. The schematic diagram for a tuned diode receiver.

circuit you used in Chapter 11, "Resonance and Tuning." The layout for a small circuit board and the schematic diagram for a crystal detector set are shown in Figs. 542 and 543.

This is the same circuit you used in Fig. 157 but with a crystal diode replacing the tube. A loopstick has been substituted for the antenna coil. You may use either a standard size or a miniature tuning condenser to keep the board size small. The values of the condensers are given on the circuit diagrams.

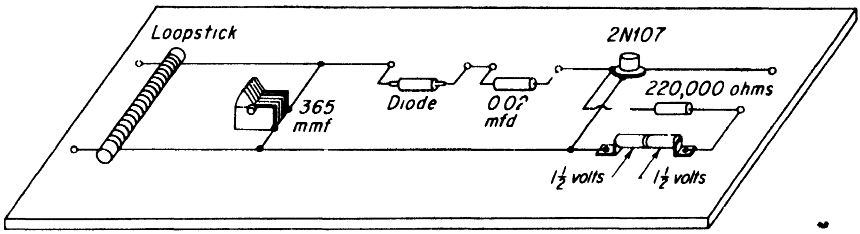


FIG. 544. The board layout for a diode-transistor receiver.

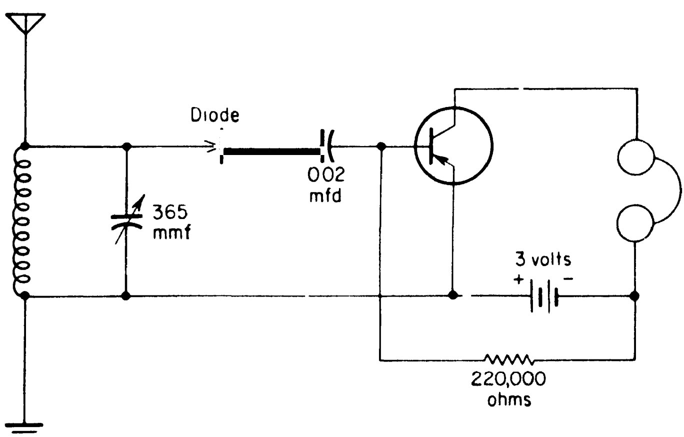


FIG. 545. The schematic diagram for a diode-transistor receiver.

Build and Wire a Diode-Transistor Set

Build this set on a ⅛-in. × 3-in. × 6-in. baseboard. Mount the loopstick, the condenser, the transistor socket, and the clips as shown in Fig. 544. If you prefer, you may use a standard replacement antenna coil for the loopstick. Note that this board layout has no soldered connections to the diode or to the transistor. The

diode may be connected to the clips. The transistor is plugged into the socket.

Soldering caution. Since heat will injure or destroy both the diode and the transistor, you must take certain precautions if you decide to solder either into the circuit. The manufacturers recommend the use of a *heat sink* when soldering. This means that you should grasp the connection wire for the diode with needle-nose pliers as you solder the connection (see Fig. 546). The pliers, held

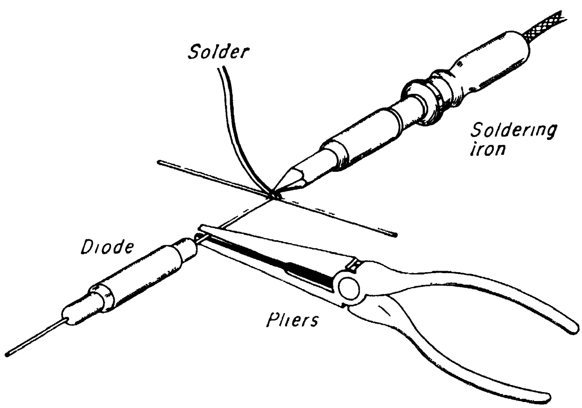


FIG. 546. Grip the pigtail wire with pliers so that heat from the soldering iron will be absorbed by the pliers instead of reaching the diode.

next to the diode, absorb the heat in the wire so that it does not reach the diode. Do the same when soldering to the transistor lead wires. Some constructors place a wet rag around the diode or the transistor to absorb or "sink" the heat.

How to Operate the Diode-Transistor Set

Attach the antenna and ground to the set. Attach the earphones. When you place the two Penlite cells in their clips, the set is in operation. Be sure to remove the batteries when you are through with this experiment.

How to Build and Wire a Two-transistor Set

Build this set on a $\frac{1}{8}$-in. × 3-in. × 6-in. baseboard (see Figs. 547 and 548). Mount the tuning condenser, the loopstick, the transistor sockets, the volume control, and the coupling transformer as

shown in Fig. 547. You may use a switch for the batteries or you may slip the batteries in clips to turn on the set.

Add the necessary clips for antenna and ground connections and for the earphones.

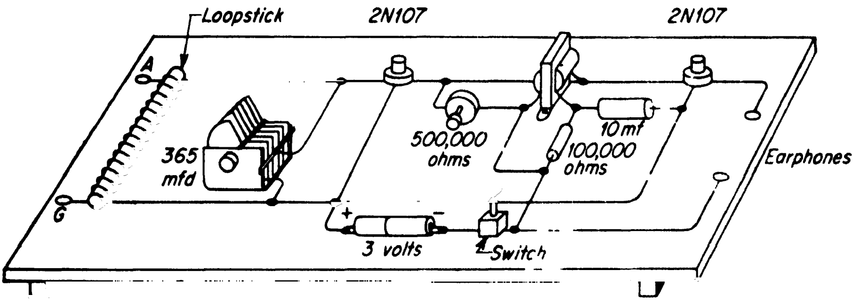


FIG. 547. The board layout for a two-transistor receiver.

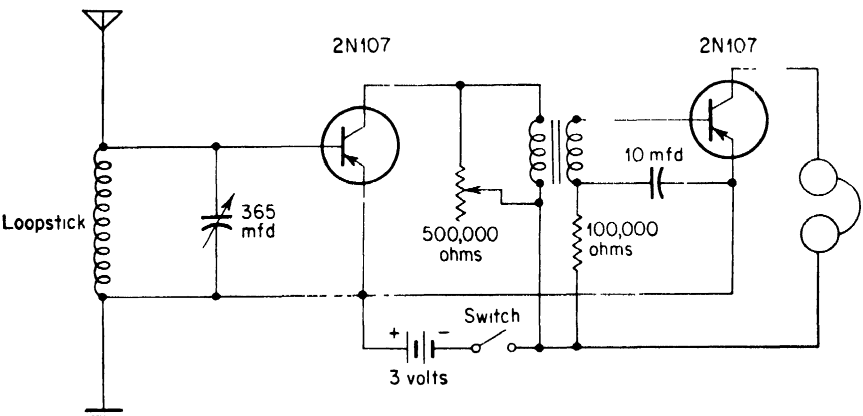


FIG. 548. The schematic diagram for a two-transistor receiver.

How to Operate the Set

Simply turn on the switch or clip in the batteries and this set is in operation. You will like the two-transistor set because of the long life of the batteries and the lifelike quality of the voice and music.

CHAPTER 27

LOOKING AHEAD IN RADIO

Your new radio knowledge derived from your experience in operating the radio circuits described in this text will have many uses. Now it is time to learn about the different ways in which these radio principles and circuits are at work in industry, in business, and in science. Learn, too, about some of the things that radio may be doing in the future. It is time to think about finding a place in which to use your new radio knowledge.

During wartime you read of the marvelous things done with radar, with the night-vision scope, with the walkie-talkie, and with dozens of other pieces of specialized equipment. You have probably read about the development of uranium and atomic research or about the atomic-fission processes.

The list of radio applications is literally endless. You are amazed at the immense scope of the applications reported in radio or electronics magazines. You read about radio circuits used for sorting beans. You find radio equipment replacing the navigator and steering a ship through darkness or fog with unerring accuracy. You find it measuring the thickness of materials as they issue from machines at express-train speeds. Your doctor uses heat generated by radio diathermy to bake soreness out of your muscles. A radio circuit stops the carriage in a sawmill before a hidden spike grown into the log can wreck the whining saw.

You can talk from a speeding train to your family or to your business a thousand miles away. You can literally talk to any place in the world which has radio or telephone equipment. A radio link operating automatically and with only routine care bridges the gap in a telephone line destroyed by storm or accident. These few uses hint at the many ways in which radio is used and at some of the directions in which its development is going.

Perhaps their complexity makes these developments seem mysterious and beyond your understanding. Yet when you examine

their circuits, you find that most of them use the simple basic electrical and radio facts which you have studied. You recognize in them some application of the principles of magnetism, of current and voltage, of the vacuum tube, and of radio frequencies in different circuit arrangements.

Each of the thousands of vacuum tubes and circuits used in the electronic calculator is simply an adaptation of a basic vacuum-tube circuit which you have studied and used in the experiments described in this book. In the radar system which brings a plane to a safe landing on a foggy field you find familiar circuits. The klystron tube and the magnetron you recognize as advanced developments of the vacuum-tube principle. You will, of course, need much more training in each of these fields before you are capable of taking your place in them.

Now examine radio broadcasting, one of the more common fields of radio, to discover the opportunities it holds for you, a new radioman.

The Standard Radio-broadcasting Industry

You will be interested in three phases of the radio-broadcasting industry: design and manufacturing, the broadcasting station, and radio-receiver maintenance.

Your home radio receiver is the product of a series of radio occupations which start with the design process. Its circuits were designed and tested by radio engineers. Then, during manufacture, many unskilled and semiskilled people form the different parts and assemble and wire them into a complete radio set. The set is tested by trained radio technicians before it is packaged and shipped.

Opportunities in radio engineering require four to five years of highly technical study in college. Manufacturing jobs are done by women and by machine operators who need little or no radio training. The technicians who test the finished sets must be well-trained radiomen.

Broadcast stations are adjusted and maintained by operators who must be thoroughly trained and who must pass a stiff technical examination to earn their Federal operator's license. They must have considerable technical experience with different types of equipment.

Radio servicing can be learned in several months of vocational training. While there is an oversupply of poorly trained servicemen, there are always openings for competent, fast workers.

Broadcasting Today

Broadcasting today is facing many technical problems. One of these is the problem of frequency allocations. Broadcasting stations now operate somewhere within a band of frequencies about 1000 kilocycles wide, from 550 to 1500 kilocycles. These frequencies are assigned by the Federal Communications Commission as part of an international-frequency agreement. Since radio signals from Europe, Africa, South America, and even from Australia reach your home and can be heard if your set will operate on the proper frequencies, the frequency allocations of one country affect reception in every country on the globe. International conferences, held at about 10-year intervals, consider new developments and make adjustments in the frequency allocations.

The broadcast-station frequencies were originally chosen for use by relatively low powered stations serving local communities. Stations at a considerable distance apart, it was thought, could share the same frequency allocation without interfering with each other's signals. A relatively few high-powered stations were also authorized. Yet on cold, clear nights, you have heard stations thousands of miles away as clearly as if they were in the next town.

Because signals on the broadcast frequencies would, under the proper conditions, carry great distances, foreign countries have long been interested in these frequencies for communication purposes.

The allocation problem is further complicated by the heavy demand for frequencies by new broadcasting stations, because the number of available channels has been exhausted. New stations must wait for released frequencies.

Sometime in the future, most of the channels now used for broadcasting may be allocated for other use. Broadcasting will probably be moved up to the very high frequency bands where many more channels are available. Because stations operating in these frequencies have an effective range of 50 miles, well-separated stations can then share frequencies. This will make it possible for more stations to operate in the new broadcast frequencies.

Such a frequency change will open many new opportunities for

trained radiomen. Factories in which the sets are designed and built will need workers. The radio stores from which your new set is purchased will need men for installation and servicing.

Frequency-modulation Broadcasting

Frequency modulation, with the possibility of high-fidelity music untroubled by noise and static, has been held back by technical problems of program transmission and by the development of television. Yet the time will come when all sound is handled by frequency modulation as an important part of television entertainment.

The absence of interference from static and noise as well as its other advantages have made frequency modulation popular for many industrial and commercial applications.

Mobile Two-way Communication

Frequency-modulation equipment is rapidly becoming standard for a host of mobile communication uses. Police were early users of frequency-modulation equipment because it gave positive and dependable two-way communication. The amplitude-modulation equipment which was first used had considerable interference from static and noise and was bothered by skip. Frequency modulation is now standard police equipment.

This mobile police equipment has gone through four distinct stages of technical development. You may recall the first amplitude-modulated police radio equipment with its long whip antennas, operating on frequencies of 1600 to 2400 kilocycles. In the second stage the frequency was raised to a band between 30 and 40 megacycles to improve the reliability of operation. Signals on these early amplitude-modulation sets were often blanked out when there was static and when the cars were near metal warehouses or in deep, canyonlike streets where reliable communication was urgently needed.

Present police radio equipment, in its third stage, uses frequency-modulation circuits and operates on the 152- to 174-megacycle channel. You have noticed the tiny antennas on the present police cars and motorcycles. The increasing demand for frequencies by new services may force police radio into its fourth stage. The police channels may be changed to the 450- to 470-megacycle

band, or even higher. Skip and interference on these higher frequencies are greatly reduced or are eliminated.

Fire apparatus and fire chiefs' cars now use cars equipped with frequency-modulation. According to experts, fires are fought successfully or the battle is lost in the first few minutes of the blaze. A chief at the scene of the fire can call extra equipment by radio and then direct the firemen at work on the blaze by means of loudspeakers.

Less well known but equally valuable are the radio cars used by the sheriff and his staff. These men are responsible for law enforcement outside the cities, which are covered by the regular police force.

The great utility of the police radio equipment showed the way to the road-maintenance divisions of state and county highway departments. Accidents which damage roads or bridges are reported by radio to maintenance headquarters, and the men and equipment are on hand in minimum time. Debris, wrecks, injured persons, washouts, collapsed or damaged bridges, all are quickly taken care of so that traffic can move again.

Radio takes to the air to locate snowbound trucks and cars or, in times of flood, to locate stranded persons and to direct relief to them.

The value of radio to business is dramatically shown by the adoption by taxicab companies of mobile frequency-modulation equipment. The cost of the whole installation is quickly paid off by the savings in mileage and repairs made possible because drivers can call the dispatcher to find their next fare without returning to their stand. The added profits are very attractive, according to companies using this equipment.

Some taxicab companies put their calls on the air over a local frequency-modulation broadcasting station, operating on frequencies near those used for the regular frequency-modulation broadcasts.

Frequency-modulated equipment is valuable for these different services because it is quiet in operation, speech is clear-cut, and the signals have uniform strength. These characteristics make important conversations easy to carry on. The fading found in amplitude-modulation reception is absent.

Within its reliable operating range of about 50 miles, the volume of the signal is nearly constant. Beyond this range the signal is

often too weak to provide proper limiting action. When the signal from the transmitter is over a certain strength, the limiters maintain the sound at constant volume and they also kill noise and static. Beyond this operating range, the weaker signal reduces the effectiveness of the limiters and some noise and fading are heard.

How do these uses of frequency-modulation mobile equipment affect you? There are many opportunities opening up in this new field. Men are needed to install and to maintain this equipment. Screw-driver mechanics are too poorly informed technically for this kind of work. Thorough training and diagnosing skill are needed. You have the basic training for this kin l of work.

Television Sight Comes to Radio

Television is a gold mine for radio dealers and for men who install and adjust the sets. While television goes through several years of development, while new ideas and new equipment are being introduced to the public, there will be many business opportunities for you in television.

Perhaps you will start by installing new sets, antennas, transmission lines, and answering calls to teach new set owners how to get good pictures. Later, you will do simple servicing, replacing parts under the watchful eye of an experienced serviceman as you learn the ropes. You will need further training to do adjustment and realignment as well as the more complicated servicing jobs. But what is the future in this field?

Television is still new enough to challenge the imagination. Color television is coming out of the research stages and soon will be broadcast to an increasing number of localities. Technical reports mention larger viewing screens for the home, the projection tube, and large-screen projection for the theater. Special programs may become available through the facilities of the telephone company. If this development is adopted widely, you will be able to choose special programs that will be transmitted in part over the air and in part by a special connection to the regular telephone lines.

Home television receivers seem to be following the trend of the amplitude-modulation radio sets which at first were expensive, large, and complicated. Radio cabinets became smaller, better circuits were developed, and better reception was had because of

the improved circuit design. In television the viewing tubes are growing in size.

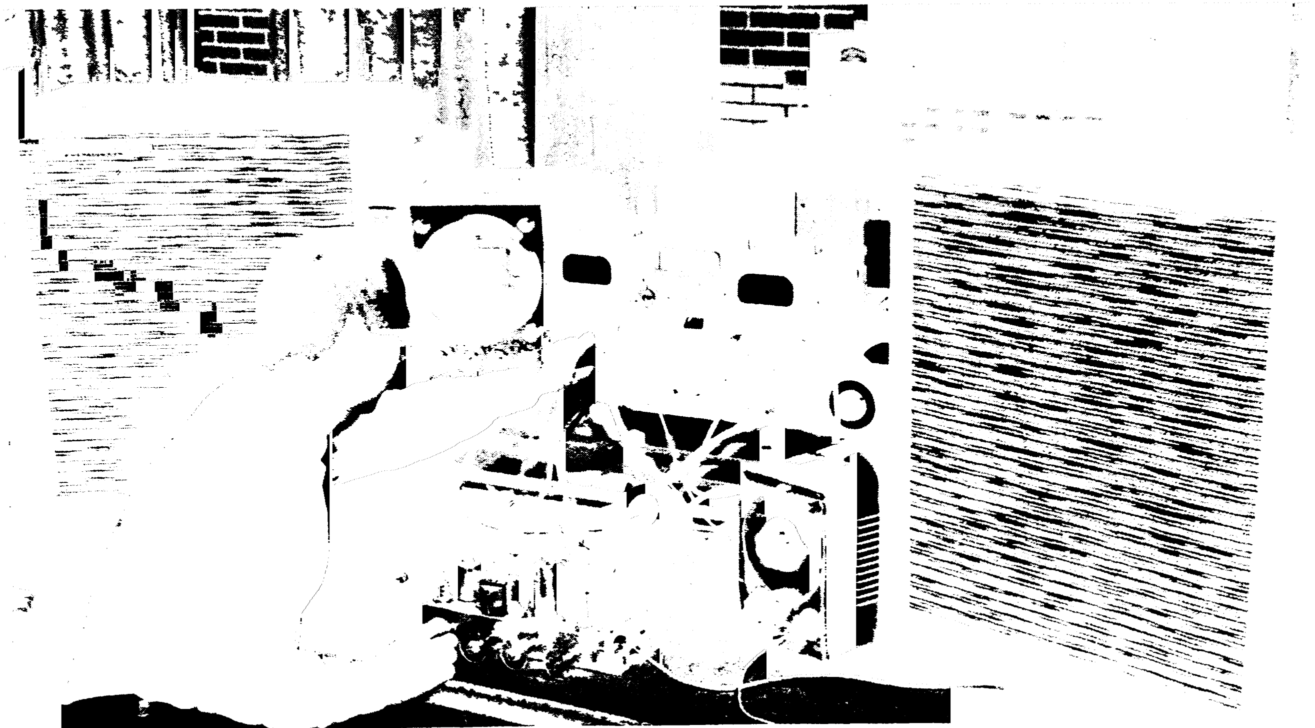
Television network problems. Radio networks such as the National Broadcasting System, the Columbia Broadcasting System, and the Dumont System have made possible the widespread transmission of radio programs all over the country. Networks have made good radio programs widely available and have spread their cost.

A nationwide network for television is desirable, but a system similar to that used for amplitude modulation is impractical. Amplitude-modulated radio programs distributed over networks from Radio City and other centers reach your local radio station over special long-lines telephone circuits. But the long lines are incapable of handling satisfactorily the very wide range of frequencies needed by the television programs. One satisfactory substitute seemed to be the coaxial cable. Yet this cable not only proved to be too expensive but introduced so much distortion into the program as to be impractical for television use over long distances.

Television repeater stations. Fixed or air-borne repeater stations seem to be the answer to the television-network problem. In each repeater station a very high frequency receiver picks up the signal and automatically feeds it to a transmitter which puts the strengthened signal back on the air. A difference of a few megacycles in frequency is used to prevent feedback. The television-network repeaters are spaced about 50 miles apart in flat country. In mountainous country the repeaters may be as much as 150 miles apart and still be in line of sight.

Directive antennas build up the strength of the repeater signal and confine its radio wave into a beam to prevent interference with other services. By using only radio frequency, the losses caused by the repeater process are kept so low that distortion can only be measured by using many multipliers. This method promises practically distortionless television-network programs.

Many competent construction and maintenance men will be needed to keep the repeater equipment in good operating condition. You can get some idea of the need for operators when you count up the number of repeaters in a single 3000-mile coast-to-coast line of repeater stations.



Electronics

TESTING STEREOPHONIC AMPLIFIER FOR HOME PHONOGRAPHS

One manufacturer, in attempting to supply high-quality stereophonic equipment for home use, has designed a single amplifier to take the place of dual amplifiers Here the new amplifier is being tested.

The repeater system is more reliable than are telephone lines under severe storm conditions. The repeaters have no overhead wires to break down under ice loads or heavy winds.

The problem of providing television programs for small communities may be solved by an interesting application of the repeater-relay station. Few small communities can support a regular television broadcasting station, but they can have television programs by installing an automatic repeater on a high point near the town or locality to be served.

The small transmitter in the automatic repeater, of about 15 watts output, sprays the locality with television programs picked up from the nearest network repeater-relay station. Commercial announcements and other soundcasts can be inserted into the television-program breaks by a local station operator. He breaks into the television program, blanking it off the air for his announcements by means of a low-powered transmitter.

Commercial Uses for Television. There are many business possibilities for television. Auto-parts and auto-supply houses may use two-way equipment to check orders for parts improperly listed or not shown in their catalogues. By holding the part before the television camera and talking directly to the supply house, the salesman can obtain the part quickly for the waiting customer.

Time, in this case, is important. The television equipment eliminates time-consuming correspondence. Several letters may be needed to clear up a point which can be handled in a few minutes of conversation over the two-way television equipment.

Conferences held by television cover more information in a few minutes than will pages of correspondence. Sketches, drawings, and parts can be shown and discussed, and decisions can be reached quickly over television hookups.

The television camera set up to direct the remote-controlled handling of radio-active material points the way for handling other dangerous operations. A television camera monitoring instruments during the dive of a bathysphere will provide a running record of the conditions met in a dive too deep and dangerous for a man to undertake. The marine version of the television camera can be used to direct salvage operations and to examine wrecks. It can also be used on underwater construction or on exploration work.

It is easy to imagine the television camera providing ground observers with data during the flight of research rockets into the higher upper air. The first experimental space ship will be able to send back data by means of a television camera and may use television to direct control during flight as it roars its way through the high ionosphere into interstellar space. Perhaps the television camera will send back an electronic-eye view of interstellar space for future study and use.

All this equipment requires trained personnel for its installation and must be constantly maintained by competent servicemen.

Automatic Repeater Stations

Policing the Pennsylvania Turnpike was a problem when it was first built because the route of this fast motor highway followed an old railroad right of way through a mountainous region. The police radio frequencies used then were blanked out by radio shadow created by the hills and mountains through which the Turnpike ran. Repeater stations were placed on mountain tops, where the police radio cars were always in line of sight with a repeater station. This made communication with the central station easily possible via the radio-repeater relays.

Facsimile

Facsimile combines light beams, the photocell, and a photographic process to transmit photographs or any other printed or written material by radio or wire. In the facsimile process, a picture placed on a rapidly revolving cylinder is scanned by a spot of light. The light reflected from the light and dark areas controls the voltage delivered by the photocell. These varying voltages are amplified and sent out by radio or wire to the distant facsimile receiver.

At the receiver, the intensity of a light spot, controlled by the received voltages, affects the sensitized paper on a rotating cylinder. A duplicate, or facsimile, of the picture at the transmitter is produced when paper is developed by a chemical process like that used in photography. Newspaper photographs from foreign countries are received by this method.

Business can use facsimile to handle urgent correspondence between branches located in different cities. An entire letter can

be transmitted in minutes where days would be required for it to reach its destination if it were sent by regular mail. Urgently needed drawings for a manufacturing process, for design data to be checked, or for the judgment of a distant consultant can be handled by facsimile.

There are opportunities in facsimile for operators and maintenance men. Some experience in photography is also a valuable asset.

Carrier Equipment

Electric power lines have long been used as a carrier for telephone signals by power companies. The telephone frequencies are introduced onto the power lines by special radio circuits which operate on a band of frequencies between 20 and 100 kilocycles.

The carrier telephone service is used by operating personnel between power stations along the power lines. The conversations pass over the power wires. Telemetering signals also operate over the carrier equipment to bring to the central station automatic information such as the height of water in a power dam, the amount of water flowing through turbines driving a generator, or the readings of meters and gages in a distant power station.

Chemical companies get the readings of meters and gages to a central location by telemetering circuits operating over the regular power lines running through the plant. Equipment installations are often located in positions difficult to reach.

The carrier principle is also used to protect power lines from shorts, lightning, and other accidents which throw sudden, damaging loads on the lines and station equipment. This system uses radio-frequency signals on the power wires to operate protective equipment.

When a storm drops a tree across the power wires or when lightning strikes the line, the generators at the central station are protected by circuit breakers which are operated by the sudden increase in current. When an accident occurs on a line protected by carrier equipment, the radio-frequency signal operates the circuit breakers before the heavy current load reaches the station. The carrier signals may even be used to switch the damaged lines out of the system and transfer their load to another circuit. This action takes place so fast that the power consumer notes no

power failure and his service is uninterrupted. The carrier system will operate over distances of about 110 miles.

The men who install and maintain carrier equipment for the power companies are generally specialists, men trained either for power work with special carrier-work training added or for radio work with the training adapted to this special job on the power lines and equipment.

The telephone companies use many men in their construction departments for installation, as well as for maintenance and operation of the equipment. These men receive considerable on-the-job instruction in the specialized procedures used by the telephone company, and this helps to upgrade them. Radio circuits and radio principles are used in the long-lines department of the telephone company and in the carrier system, where multiple operation is used to handle hundreds of conversations over a single pair of wires. Radio training is needed by the men who maintain the repeater equipment used on the long lines. Some of these men must have Federal operators' licenses to maintain and adjust the transmitting equipment.

Telephone-maintenance men use the carrier system for conversations about their work. It is odd to watch a maintenance man use an ordinary telegraph key and sounder to call maintenance at another station and discuss a technical problem while sharing a pair of wires with several hundred other business messages or personal conversations.

Industrial Electronics

The application of radio principles to industrial electronics is an entire field in itself. Many electronic applications use the principles of rectification and of grid control, with which you are familiar. Heavy alternating currents rectified by huge tubes, vacuum-tube circuits used in welding circuits, and tube circuits which change direct current to alternating current are some of the interesting applications you will find in industrial electronics.

You will find circuits operated by the photocell or the so-called *electric eye* controlling manufacturing processes. Beans are sorted, color is matched, materials are inspected during manufacture, and so on, for an infinite number of uses. The automatic door opener is a common example of an electronic circuit at work.

Radio transmitter circuits also find industrial uses. Radio-frequency power is used in the manufacture of flat sheets of plywood and of molded plywood articles. Radio-frequency heat generated in the glue cures the wood in minutes where in the older steam presses hours were required for heat to penetrate the stack of plywood.

The diathermy in the doctor's office is a good example of the familiar radio transmitter circuit in an electronic application.

Foods are pasteurized by supersonic vibrations produced by radio-frequency oscillators.

Factories use radio-trained maintenance men to keep the electronic equipment in good operating condition. The equipment is installed by factory men, and a factory-trained man at each sales-district office is available for consultation and for special maintenance problems.

Atomic Energy and Nuclear Physics

Radio has already played an important part in the development of atomic energy and atomic fission. Radio equipment and many radio principles assist basic research into the nature of the atom. In the cyclatron atomic particles were whirled about in a vacuum by energy supplied by radio-frequency power circuits. Separation of uranium isotopes was assisted by knowledge of principles similar to that governing the action of the vacuum tube. Many of the control processes in the manufacture of atomic materials are said to be electronic in nature.

The Geiger counter, used to detect radiation, includes a vacuum-tube amplifying circuit. When the curtain of secrecy about the atom-separation process is lifted, the radio and electronic fields will be enriched by many new and valuable processes.

It was difficult to study the atomic structure of molecules by means of infrared (infra-red) light because the particles moved too fast for easy study. When microwave frequencies were used, the motion of the particles was slow enough for easier study.

Radar

Radar, so highly developed during wartime to detect and to range enemy aircraft, is finding many peacetime uses. Radar-equipped planes are being used to study hurricanes. Operators

on these planes, stationed in the hurricane area, locate and track these destructive storms by watching the eye of the storm on the radar scope. They plot the track and radio back to their stations, which warn ships and cities that might be in the storm paths.

The larger passenger ships are being equipped with radar to increase safety in navigation through iceberg areas or through fog. Radar-equipped cargo-carrying vessels can proceed through dense fog on long river approaches to inland harbors. Without radar, the vessel must tie up and wait for clear weather before proceeding to its destination.

The Columbia River approach to the Portland, Oregon, harbor, 100 miles from the ocean, is an example. Radar has been used on the run from San Francisco Bay to the inland harbor at Stockton, California, and in the Sault Sainte Marie canal in the Great Lakes area.

Airlines have faced serious landing problems at night, during fog, or in snowstorms. Airports and planes are being equipped with a radar landing system which permits planes to land in complete darkness or in impenetrable fog. Travelers down the West coast are intrigued by the forest of poles, lights, and other technical landing equipment at Arcata, California. Arcata was selected as the location of a research station to study different systems of landing airplanes in foul weather.

The remarkable record of the thousands of landings and take-offs made on the Berlin airlift was possible because radar directed the planes on and off the fields under all sorts of weather conditions.

Your Opportunity in Radio

Where will you fit into one of these many branches and applications of radio? You have found radio used in some form everywhere you turn. In one of these branches you will be able to find a starting place and later on a permanent berth. But until you find your place in radio, keep up with the art.

Keep up to date. One way to keep up to date is to make amateur radio your avocation. Build and erect your own transmitter, and become one of the army of "hams" visiting by code or voice over the air. In the process of building and operating your own equipment, keep abreast of new developments not only by reading but by experimenting.

The exploits of the radio hams in times of disaster, the amateurs who formed the backbone of the armed-forces communications system in wartime, are well known. Less is known about the peculiarly fine training gained and the ingenuity and experience developed by hams in their endless experimenting and rebuilding to make

Bell Laboratories Record

TESTING A SOLID-STATE MASER

The material being tested is placed in a resonant cavity maintained at an extremely low temperature by liquid helium. The Maser amplifier will be used in repeater circuits and to increase the range of radio telescopes.

their equipment more efficient and able to operate over longer distances. This training and experience lead into many fine radio opportunities.

Do you like construction? Perhaps your interest in construction has been aroused. You have just learned about some of the places in which there is a growing need for men to install and to maintain every type of radio equipment.

Television offers a host of opportunities. New television stations being built will need operators and maintenance men. Technical help is needed in studios. Thousands of new and well-trained television servicemen will be needed.

Radio-service trades offer openings. The greatest opportunities seem to be developing in the radio-service trades. There is great need for *well-trained* men to service home radio and television equipment. There is a growing need for men capable of installing and maintaining the equipment used by radio-equipped mobile services.

Radio servicing is a good way to start your own business. Such work is steady and may often be combined with sales into a small business opportunity. The growth of such a business depends on your initiative and the possibilities in your own community.

Television requires even better trained and more experienced servicemen than does the amplitude-modulation radio. The greater technical complexity of television equipment and circuits requires excellently trained men who are not only good mechanics but also understand the operating theory of the equipment.

The salesman of mobile radio equipment must understand the design and operation of his equipment and how it will serve his prospective customer. He must know the equipment well enough to be able to discuss with his prospect the service that can be expected from it as well as its limitations.

Your Future Development

Few radiomen ever feel that they know enough about their subject. Radio is so extensive and there is so much to learn about it that when one book is mastered you may want to move on to more advanced radio training.

Now that you are ready to go on with your study, you will find extensive lists of books to select from. Here is a list of radio texts and handbooks for your selection, grouped into the different fields in which you may wish to work.

For the Radio Amateur

There are two outstanding magazines which describe new circuits and equipment and cover the field of amateur activity. One, *QST*, is published by the American Radio Relay League, a strictly

amateur organization. This magazine was started in 1915 and has been a leader in American amateur-radio development ever since. Each year this group puts out an authoritative handbook on new circuits, set construction, operation, and general amateur communication practice.

The other amateur radio magazine is called *CQ*. It also deals with amateur equipment and operating problems. *The Radio Handbook* is an excellent amateur handbook.

Magazines

QST, published by the American Radio Relay League, West Hartford, Connecticut.

CQ, published by Cowan Publishing Corporation, New York, New York.

Handbooks

The Radio Amateur's Handbook, Headquarters Staff of the American Radio Relay League, West Hartford, Connecticut.

The Radio Handbook, Editors and Engineers, Los Angeles, California.

For Further General Radio Study

A group of excellent radio texts are listed here. You may select books from this list to study nearly any phase of radio. The first list includes texts which go further into radio theory. They include mathematics, which you will need in your advanced radio study.

The radio amateur, the radio serviceman, and the radio experimenter can get by with a minimum of mathematics only by working by rule of thumb, by trying things and remembering what happened. His knowledge is inexact, and he is only a mediocre radioman clever at guessing his way through his problems. His future in radio is definitely limited because he is unable to think his way through the complicated situations with which radio abounds.

Mathematics is a "must" for radio engineering and research. Basic engineering math requires a thorough grasp of algebra, trigonometry, geometry, analytical geometry, and calculus, as well as differential equations. This basic math is used constantly in

all phases of radio engineering. Radio engineering requires four or five years of work in any good college. "Quickie" or home-study courses are a poor substitute for the broad and thorough training you can get in a regular college course.

Use this list of books to build up your information and to help you to prepare for more advanced training.

Essentials of Electricity for Radio and Television (2d ed.), M. Slurzberg and Wm. Osterheld, McGraw-Hill.

Essentials of Radio, M. Slurzberg and Wm. Osterheld, McGraw-Hill.

Principles of Radio, Keith Henney, Wiley.

Basic Radio, J. Barton Hoag, Van Nostrand.

Introduction to Practical Radio, D. J. Tucker, Macmillan.

Mathematics for Electricians and Radiomen, Nelson M. Cooke, McGraw-Hill.

Electronics Dictionary, Nelson M. Cooke and John Markus, McGraw-Hill.

Fundamentals of Radio, F. E. Terman, McGraw-Hill.

Inside the Vacuum Tube, John F. Rider, John F. Rider.

FM Simplified, M. S. Kiver, Van Nostrand.

Television Simplified, M. S. Kiver, Van Nostrand.

Understanding Microwaves, Victor J. Young, Van Nostrand.

For Radio Servicing

Elements of Radio Servicing, Wm. Marcus and Alex Levy, McGraw-Hill.

The series of books and pamphlets published by John F. Rider.

For Radio Operating

Radio Operating Questions and Answers (12th ed.), J. L. Hornung and A. A. McKenzie, McGraw-Hill.

Practical Radio Communication (2d ed.), Arthur R. Nilson and J. L. Hornung, McGraw-Hill.

Your Future Radio Training

Plan your future training program carefully. Take care of your immediate technical training, but also include a good general education. Avoid a common mistake made by younger trainees; they become so fascinated by the technical and operating details of radio that they go overboard and miss their general education.

Complete your high school training, your junior college training, and continue your general education as far as you can go. Remember that your general knowledge and your ability to get along with people, and not just your technical training, help you to get and to keep your job. A college training is worth while if you are willing to do the necessary hard work. A college degree opens up a whole group of jobs to you. Your future is determined by the extent of your training, by its thoroughness, and by your own initiative and energy. Avoid too early and too narrow a specialized training.

RADIO-TUBE CHARACTERISTICS CHARTS*

Two radio-tube characteristics charts are given in the pages that follow. The first is a Selected Tube List for quick, handy reference. The second is a Condensed Data Section that includes a larger and more complete list of tubes.

The Selected Tube List. This selected list includes only the tubes used or recommended for the experiments and the circuit boards described in this book. This convenient list enables you to find quickly the information about the tube you are working with together with its base diagram and its operating characteristics instead of searching through the much larger list given in the Condensed Data Section.

The Condensed Data Section. This is a more complete list of tubes commonly used in radio and television circuits. Students who wish to substitute higher-performance tubes for the simpler, more basic tubes used in the text and shown in the Selected Tube List and those who wish to do advanced experiments may select tubes with similar characteristics from the Condensed Data Section.

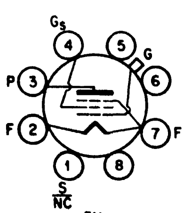
The meaning of the symbols in the different columns of the Selected Tube List is given in the following section "How to Use the Selected Tube List." This explanation is unnecessary for the simpler form used in the Condensed Data Section.

How to use the Selected Tube List. The types of tubes are listed in numerical and alphabetical order. The third column lists the style of construction. Lock in, Miniature, and GT are, of course, well-known, but the letters "ST" may need explaining. ST is the dome-topped bulb as now used in type 25Z5, etc. The number following ST gives the nominal maximum diameter in eighths of an inch.

The column "Base Diagram" shows that the base for type 7B7 is 8V-L-5. This means that the active elements are connected as shown in the base diagram 8V, and that the external shielding (in this case the lock-in base) is connected to the lug (L) and the internal shield to pin 5. This avoids having a separate base diagram for types with a minor difference in shielding.

* The data given here have been compiled from various sources by the Commercial Engineering Department of Sylvania Electric Products, Inc., Emporium, Pennsylvania.

Type	Class	Construction		Emitter			Use
		Style	Base diagram	Type	Volts	Amp	
1N5GT	Pentode	GT	5Y-1-7	Filament	1.4	0.05	R-F amplifier
1S5	Diode pentode	Miniature	6AU-0-0	Filament	1.4	0.05	Det amplifier
5Y3GT	Duodiode	GT	5T-0-0	Filament	5.0	2.00	F-W rectifier
5Z3	Duodiode	ST-16	C4-0-0	Filament	5.0	3.00	F-W rectifier
6AC7	Pentode	Metal	8N-1-1	Cathode	6.3	0.45	Amplifier
6C5	Triode	Metal	6Q-1-1	Cathode	6.3	0.30	Amplifier
6F6	Pentode	Metal	7S-1-0	Cathode	6.3	0.70	Power amplifier
6H6	Duodiode	Metal	7Q-1-1	Cathode	6.3	0.30	Rectifier
6J5	Triode	Metal	6Q-1-0	Cathode	6.3	0.30	Amplifier
6K7	Pentode	Metal	7R-1-0	Cathode	6.3	0.30	Amplifier
6L6	Beam amplifier	Metal	7AC-1-0	Cathode	6.3	0.90	Power amplifier
6V6	Beam amplifier	Metal	7AC-1-0	Cathode	6.3	0.45	Power amplifier
6X5	Duodiode	Metal	6S-1-0	Cathode	6.3	0.60	F-W rectifier
7B7	Pentode	Lock in	8V-L-5	Cathode	6.3	0.15	Amplifier
7C5	Beam amplifier	Lock in	6AA-L-0	Cathode	6.3	0.45	Power amplifier
25L6	Beam amplifier	Metal	7AC-1-0	Cathode	25.0	0.30	Power amplifier
25Z5	Duodiode	ST-12	6E-0-0	Cathode	25.0	0.30	Doubler H-W rectifier
35L6GT	Beam amplifier	GT	7AC-0-0	Cathode	35.0	0.15	H-W rectifier
35Z5	Diode	GT	6AD-0-0	Cathode	35.0	0.15	H-W rectifier
807	Tetrode	ST-16	5AW	Cathode	6.3	0.9	Beam amplifier
T20	Triode	....	....	Filament	7.5	1.75	Power amplifier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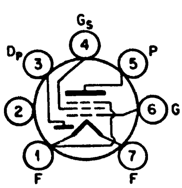
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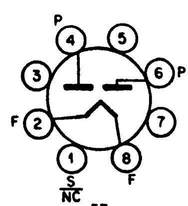
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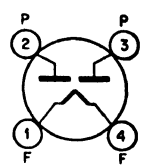
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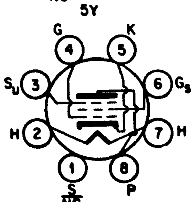
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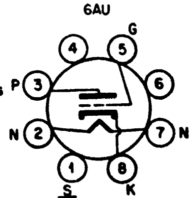
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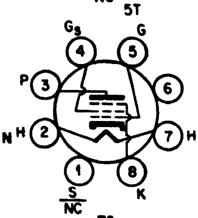
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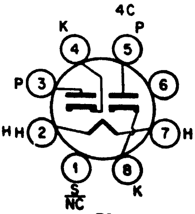
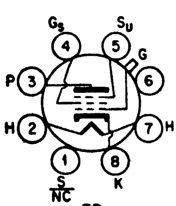

7Q

TUBE LIST

Plate volts	Screen volts	Negative grid volts	Plate current, ma	Screen current, ma	Plate resistance, ohms	Amplification factor or G_m in micromhos	Power output, milliwatts	Type
90	90	0 0	1 2	0 3	1 5 meg			1N5GT
67 5	67 5	0 0	1 6	0 4	600,000			1S5
350 ac volts per plate, rms, 125 ma output current, condenser input to filter								5Y3GT
500 ac volts per plate, rms, 125 ma output current, choke input to filter								
450 ac volts per plate, rms, 225 ma output current, condenser input to filter								5Z3
300	150		10 0	2 5	1 0 meg	6,750 bias res = 160 ohms		6AC7
250		8 0	8 0		10,000	20 0		6C5
250	250	16 5	34 0	6 5	80 000		3,200	6F6
117 ac volts per plate, rms, 8 0 ma output per plate								6H6
250		8 0	9 0		7,700	20 0		6J5
100	100	1 0	9 0	2 7	150,000			6K7
250	100	3 0	7 0	1 7	800,000			
250	125	3 0	10 5	2 6	600,000			
250	250	14 0	72 0	5 0	22,500		6,500	6L6
180	180	8 5	29 0	3 0	58,000		2,000	6V6
325 ac volts per plate, rms, 70 ma output current, condenser input to filter								6X5
450 ac volts per plate, rms, 70 ma output current, choke input to filter								
100	100	3 0	8 2	1 8	300,000			7B7
250	100	3 0	8 5	1 7	750 000			
180	180	8 5	29 0	3 0	58,000		2,000	7C5
110	110	7 5	49 0	4 0	13,000		2,100	25L6
200	110	8 0	50 0	2 0	30,000		43,000	
117 ac volts per plate, rms, 75 ma output current per plate								25Z5
235 ac volts per plate, rms, 75 ma output current per plate								
110	110	7 5	40 0	3 0	14 000		1,500	35L6GT
200	110	8 0	41 0	2 0	40 000		3,300	
235 max ac volts, rms, 60 ma output current with panel lamp								35Z5
235 max ac volts, rms, 100 ma output current without panel lamp								
750	250	−45 0	100 0	6 0			50 watts	807
600	275	−70 0	100 0	6 5			42 watts	
750		−85 0	85 0				44 watts	T20
750		−110 0	70 0				38 watts	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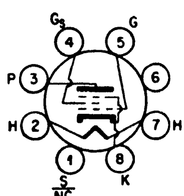
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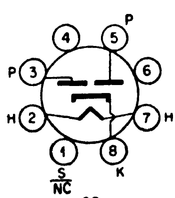
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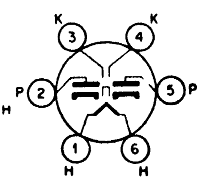
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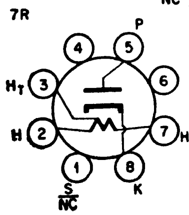
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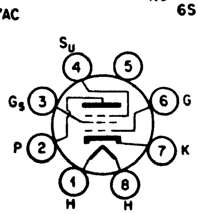
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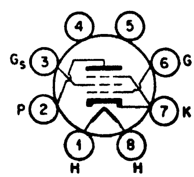
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CONDENSED DATA SECTION

TYPE	CLASS	CONSTRUCTION STYLE	CONSTRUCTION BASE DIAG	EMITTER TYPE	EMITTER VOLTS	EMITTER AMP	USE	PLATE VOLTS	SCREEN VOLTS	NEG GRID VOLTS	PLATE CUR RENT MA	SCREEN CUR RENT MA	PLATE ① RESISTANCE OHMS	AMP ② FACTOR OR Gm µMHOS	POWER OUTPUT MW	SUGGESTED REPLACEMENT TYPE
00A	Triode	ST 14	4D	Fil	5 0	0 25	Detector	45		0	1 5		30 000	20		01A
01A	Triode	ST 14	4D	Fil	5 0	0 25	Det Amp	90 135		4 5 9 0	2 5 3 0		11 000 10 000	8 0 8 0		
0Y4	Gas Diode	Metal	4BU	Cold K			H W Rectifier	117 A C Volts Per Plate RMS 75 Ma Max 40 Ma Min Output Current								
0Z4A	Gas Duodiode	T 7	4R	Ionic			F W Rectifier	300 A C Volts Per Plate RMS 110 Ma Max 30 Ma Min Output Current								
1A3	Diode	T 5½	5AP	Cath	1 4	0 15	Detector	Single Diode Cathode Type for H F Use								
1A4	Tetrode	ST 12	4K	Fil	2 0	0 06	R F Amplifier	90 180	67 5 67 5	3 0 3 0	2 2 2 3	0 9 0 8	600 000 1 0 Meg	720 750		1A4P 1A4T
1A4P	Pentode	ST 12	4M	Fil	2 0 2 0	0 06 0 06	R F Amplifier	135 180	67 5 67 5	3 0 3 0	2 2 2 3	0 9 0 8	1 Meg 1 Meg	625 725		
1A4T	Tetrode	ST 12	4K	Fil	2 0 2 0	0 06 0 06	R F Amplifier	135 180	67 5 67 5	3 0 3 0	2 2 2 2	0 7 0 7	350 000 600 000	625 650		
1A5GT	Pentode	GT	6X	Fil	1 4	0 05	Pwr Amplifier	85 90	85 90	4 5 4 5	3 5 4 0	0 7 0 8	300 000 300 000	800 850	100 115	
1A6	Heptode	ST 12	6L	Fil	2 0 2 0	0 06 0 06	Converter	135 180	67 5 67 5	3 0 3 0	1 8 1 5	2 1 2 0	400 000 500 000	275▼ 300▼	G_2=135 V at 2 0 Ma■ G_2=180 V at 2 5 Ma■	
1A7GT G	Heptode	GT T 9	7Z	Fil	1 4	0 05	Converter	90	45	0 0	0 55	0 60	600 000	250▼	E_{c2}=90 I_{c4}=1 2 Ma	
1AB5	Pentode	Lock In	5BF	Fil	1 2 1 2	0 13 0 13	R F Amplifier	90 150	90 150	0 1 5	3 5 6 8	0 8 2 0	275 000 120 000	1 100 1 350		
1AF4	Pentode	T 5½	6AR	Fil	1 4	0 025	R F Amplifier	67 5 90 0	67 5 90 0	0 0 0 0	1 0 1 65	0 3 0 5	2 Meg♦ 1 8 Meg♦	825 950		1U4
1AF5	Diode Pentode	T 5½	6AU	Fil	1 4	0 025	Detector Amplifier	67 5 90 0	67 5 90 0	0 0 0 0	0 7 1 1	0 25 0 4	2 3 Meg♦ 2 0 Meg♦	500 600		1S5
1B4	Tetrode	ST 12	4K	Fil	2 0	0 06	R F Amplifier	90 180	67 5 67 5	3 0 3 0	1 6 1 7	0 7 0 6	1 0 Meg♦ 1 5 Meg♦	600 650		1B4P 1B4T
1B4 951	Tetrode	ST 12	4K	Fil	2 0	0 06	R F Amplifier	Same as Type 1B4								1B4 P or T
1B4P	Pentode	ST 12	4M	Fil	2 0 2 0	0 06 0 06	R F Amplifier	135 180	67 5 67 5	3 0 3 0	1 6 1 7	0 7 0 6	1 5 Meg 1 5 Meg	560 650		
1B5 25S	Duodi Triode	ST 12	6M	Fil	2 0	0 06	Det Amplifier	135		3 0	0 8		35 000	20		
1B7GT	Heptode	GT	7Z	Fil	1 4	0 10	Converter	90	45	0	1 5	1 3	350 000	350▼	G_2=90 V at 1 6 Ma	1A7GT
1C3	Triode	T-5½	5CF	Fil	1 4	0 05	Amplifier	90 90		0 0 3 0	4 5 1 4		11 200♦ 19 000♦	14 5 14 5		
1C5GT	Pentode	GT	6X	Fil	1 4	0 1	Pwr Amplifier	83 90	83 90	7 0 7 5	7 0 7 5	1 6 1 6	0 11 Meg 0 115 Meg	1 500 1 550	200 240	1S4
1C6	Heptode	ST-12	6L	Fil	2 0 2 0	0 12 0 12	Converter	135 180	67 5 67 5	3 0 3 0	1 3 1 5	2 5 2 0	600 000 700 000	300▼ 325▼	G_2=135 V at 3 1 Ma■ G_2=180 V at 4 0 Ma■	
1C7G	Heptode	ST-12	7Z	Fil	2 0	0 12	Converter	Same as 1C6								
1D5G	Tetrode	ST-12	5R	Fil	2 0	0 06	R F Amplifier	180	67 5	3 0	2 3	0 7	600 000	750		1D5GP 1D5GT

1D5GP	Pentode	ST-12	5Y	Fil	2 0 2 0	0 06 0 06	R F Amplifier	135 180	67 5 67 5	3 0 3 0	2 2 2.3	0 9 0 8	1 Meg 1 Meg	625 725		
1D5GT	Tetrode	ST 12	5R	Fil	2 0 2 0	0 06 0 06	R F Amplifier	135 180	67 5 67 5	3 0 3 0	2 2 2 2	0 7 0 7	350 000 600 000	625 650		
1D7G	Heptode	ST 12	7Z	Fil	2 0 2 0	0 06 0 06	Converter	135 180	67 5 67 5	3 0 3 0	1 8 1 5	2 1 2 0	400 000 500 000	275▼ 300▼	G_2=135 V at 2 0 Ma■ G_2=180 V at 2 5 Ma■	
1D8GT	Diode Triode Pentode	GT	8AJ	Fil	1 4	0 1	Det Amplifier Pwr Amplifier	67 5 90 67 5 90	 67 5 90	0 0 6 0 9 0	0 6 1 1 3 8 5 0	 0 8 1 0	55 500 43 500 200 000♦ 200 000♦	25 25 875 925	 100 200	
1E4	Triode	T 9	5S	Fil	1 4	0 05	Det Amplifier	Same Characteristics as Type 1LE3								
1E5G	Tetrode	ST 12	5R	Fil	2 0	0 06	R F Amplifier	180	67 5	3 0	1 7	0 6		650		1E5GP, 1E5GT
1E5GP	Pentode	ST 12	5Y	Fil	2 0 2 0	0 06 0 06	R F Amplifier	135 180	67 5 67 5	3 0 3 0	1 6 1 7	0 7 0 6	1 5 Meg 1 5 Meg	560 650		
1E5GT	Tetrode	ST 12	5R	Fil	2 0	0 06	R F Amplifier	Same as Type 1E5G								1E5GP
1E7GT	Pentode	ST 12	8C	Fil	2 0 2 0 2 0	0 24 0 24 0 24	Pwr Amplifier Push Pull Max Signal	90 135 135	90 135 135	3 0 4 5 7 5	3 8 7 5 10 5♦	1 1 2 2 3 5♦	340 000 260 000 24 000♦	1 150 1 425	110 290 575	
1F4	Pentode	ST 14	5K	Fil	2 0 2 0	0 12 0 12	Pwr Amplifier	90 135	90 135	3 0 4 5	4 0 8 0	1 1 2 4	20 000 16 000	1 400 1 700	110 310	
1F5G	Pentode	ST 14	6X	Fil	2 0	0 12	Pwr Amplifier	Same as 1F4								
1F6	Duodi Pentode	ST 12	6W	Fil	2 0	0 06	R F Amplifier	180	67 5	1 5	2 2	0 7	1 Meg ♦	650		
1F7G	Duodi Pentode	ST 12	7AD	Fil	2 0	0 06	R F Amplifier	Same as 1F6								
1F7GV	Duodi Pentode	ST 12	7AF	Fil	2 0	0 06	R F Amplifier	Same as 1F7G except diodes one above the other								
1G4GT G	Triode	GT T 9	5S	Fil	1 4	0 05	Amplifier	90		6 0	2 3		10 700	8 8		
1G5G	Pentode	ST 14	6X	Fil	2 0 2 0 2 0	0 12 0 12 0 12	Pwr Amplifier	90 124 135	90 124 135	6 0 11 0 13 5	8 7 10 7 9 7	3 0 ~3 3 6	8 500 8 000 9 000	1 500 1 500 1 550	250 600 550	
1G6GT, G	Duo Triode	GT T 9	7AB	Fil	1 4	0 10	Class A Amp Class B Pwr Amplifier	90 90		0 0 0 0	1 0‡ 1 0‡		45 000	30	675	
1H4G GT	Triode	ST 12	5S	Fil	2 0 2 0 2 0	0 06 0 06 0 06	Amplifier	90 135 180		4 5 9 0 13 5	2 5 3 0 3 1		11 000 10 300 10 300	9.3 9 3 9 3		
1H6G GT	Duodi Triode	ST-12 GT	7AA	Fil	2 0	0 06	Amplifier	135		3 0	0 8		35 000	20		
1J5G	Pentode	ST-14	6X	Fil	2 0	0 12	Pwr Amplifier	135	135	16 5	7 0	1 8	13 500	1 000	450	
1J6GT G	Duo Triode	T 9 ST-12	7AB	Fil	2 0	0 24	Amplifier	Characteristics same as Type 19								
1LA4	Pentode	Lock-In	5AD	Fil	1 4	0.05	Pwr Amplifier	85 90	85 90	4.5 4 5	3 5 4 0	0 7 0 8	0.3 Meg 0.3 Meg	800 850	100 115	

① Load Resistance for Power Output Tubes
② Transconductance for Tetrodes Pentodes, Etc
▼ Conversion Transconductance

♦ Approximate
♦ Plate to Plate
■ Through 20 000 Ohms

‡ Per Tube or Section—No Signal
§ Plate and Target Supply
▲ Self Bias Cathode Resistor—Ohms

TYPE	CLASS	CONSTRUCTION		EMITTER			USE	PLATE VOLTS	SCREEN VOLTS	NEG GRID VOLTS	PLATE CUR RENT MA	SCREEN CUR-RENT MA	PLATE ① RESISTANCE OHMS	AMP ⑤ FACTOR OR Gm µMHOS	POWER OUTPUT MW	SUGGESTED REPLACEMENT TYPE
		STYLE	BASE DIAG	TYPE	VOLTS	AMP.										
1LC5	Pentode	Lock-In	7AO	Fil	1 4	0 05	R F Amplifier	45 90	45 45	0 0 0 0	1 1 0 15	0.35 0 30	0 7 Meg ♦ 1 5 Meg ♦	750 775		
1LC6	Heptode	Lock-In	7AK	Fil	1.4	0 05	Converter	45 90	35 35	0 0 0 0	0 7 0 75	0 75 0 70	0 3 Meg. 0 65 Meg.	250▼ 275▼	E_{c2}=45 V Max I_{c2}=1 4 Ma	
1LD5	Diode Pentode	Lock-In	6A X	Fil	1 4	0 05	Det Amplifier	45 90	45 45	0 0	0 55 0 6	0 12 0 1	0 9 Meg. 0 75 Meg	550 575		
1LE3	Triode	Lock-In	4AA	Fil	1 4	0 05	Amplifier	90 90		0 0 3 0	4 5 1 4		11,200 19 000	14 5 14 5		
1LG5	Semi Remote Cutoff Pentode	Lock-In	7AO	Fil.	1 4	0.05	R F Amplifier	45 90 90	45 45 90	0 0 1 5	1 5 1 7 3 7	0 45 0 4 0 9	0.35 Meg ♦ >1 0 Meg 0 5 Meg ♦	800 800 1 150	•	
1N6G	Diode Pentode	T-9	7AM	Fil	1 4	0.05	Pwr Amplifier	90	90	4 5	3 1	0 6	25,000	800	100	
1P5GT, G	Remote Cutoff Pentode	T-9	5Y	Fil	1 4	0 05	R F Amplifier	90	90	0 0	2.3	0 7	800,000	750		1N5, 1T4
1Q5GT, G	Beam Amplifier	T-9	6AF	Fil	1 4	0 10	Pwr Amplifier	90	90	4 5	9 5	1 6		2,200	270	1A5
1Q6	Diode Pentode	T-3	8CO	Fil	1.25 1 25	0.04 0.04	Det Amplifier	30 67 5	30 67.5	0 0	0.33 1 60	0 09 0 40	500,000 400,000	330 600		
1R4	H F Diode	Lock-In	4AH	Cath	1 4	0 15	Detector	117 V RMS			1 0		Resonant Frequency 1,500 Mc.			
1S4	Pentode	T-5½	7AV	Fil	1 4	0 10	Pwr. Amplifier	45 90	45 67.5	4 5 7 0	3 8 7 4	0 8 1 4	100,000♦ 100,000♦	1,250 1,575	65 270	3S4
1SA6GT	Pentode	GT	6BD	Fil	1 4	0 05	R F Amplifier	45 67 5 90	45 67.5 67 5	0 0 0	1 1 2 4 2 45	0.3 0 7 0 68	700,000 600,000 800,000	750 950 970		1N5GT
1SB6GT	Diode Pentode	GT	6BE	Fil	1 4	0 05	Det Amplifier	45 90	45 67 5	0 0	0 6 1 45	0 16 0.38	900,000 700,000	500 665		1LD5
1T5GT	Pentode	T-9	6 X	Fil	1 4	0 05	Pwr Amplifier	90	90	6 0	6 5	0 8	0 25 Meg ♦	1,150	170	1C5, 1Q5
1U6	Heptode	T-5½	7DC	Fil	1 4	0 025	Converter	67 5 90	45 45	0 0	0 5 0 55	0 6 0.55	550,000 600,000	260▼ 275▼	(Ga=67 5 V, 0 95 Ma) (Ga=90 V, 1 1 Ma)	
1V	Diode	ST-12	4G	Cath	6 3	0.30	H W Rectifier	350 V RMS Plate, 45 Ma D C Output								6Z3
1W4	Pentode	T-5½	5BZ	Fil	1 4	050	Pwr Amplifier	90	90	9 0	5 0	1 0	0 25 Meg	925	200	
2A3	Triode	ST-16	4D	Fil	2 5	2.5	Pwr. Amplifier	250 300	....	45 0 62 0	60 40 per tube	•	2,500 3,000♦	4.2	3,500 15,000	2A3H
2A3H	Triode	ST-16	4D	Cath	2 5	2 5	Pwr Amplifier	Same as Type 2A3								2A3
2A5,	Pentode	ST-14	6B	Cath	2 5	1 75	Pwr Amplifier	250 285	250 285	16.5 20.0	34 38	6 5 7 0	7,000 7,000		3,200 4,800	
2A6	Duodi Triode	ST-12	6G	Cath	2 5	0.80	Det Amplifier	250		2 0	0 9		91,000	100		
2A7, 2A7S	Heptode	ST-12	7C	Cath	2 5	0.80	Converter	Same Characteristics as Types 6A7 or 6A8G								
2B7, 2B7S	Diode Pentode	ST-12	7D	Cath.	2 5	0 80	Det. Amplifier	100 250	100 100	3 0 3 0	5.8 6 0	1 7 1 5	300,000 800,000	950 1,000		
2E5	Electron Ray	T-9	6R	Cath	2 5	0.80	Indicator	Same Characteristics as Type 6E5								
2G5	Electron Ray	T-9	6R	Cath.	2.0	0 8	Indicator	Characteristics Same as Type 6U5								2E5
2S/4S	Duo Diode	ST-12	5D	Cath.	2.5	1.35	Detector	Approximate 40 Ma. Per Plate, 50 Ma. D C Output								

2V2	Diode	T-11.	8FV	Fil	2 5 1.25	0 2 0 4	High Voltage Rectifier	TV Service Peak Inverse Volts D C=15 Kv Peak Current=80 Ma Average Current D C=2.0 Ma. Peak Inverse Volts D C=21 Kv Peak Current=80 Ma Average Current D C=1.0 Ma.								
2V3G	Diode	ST-12	4Y	Fil	2.5	5 0	H W. Rectifier	6000 V RMS Plate, 2 Ma D C Output								2X2A
2W3, GT	Diode	Metal, GT	4X	Fil	2 5	1 5	H W Rectifier	350 Volts RMS, 55 Ma Max D C Output Current with Cap. Input to Filter								2Z2
2Z2/ 284	Diode	ST-12	4B	Fil	2 5	1.50	H W Rectifier	350 Volts Per Plate RMS, 50 Ma. Output Current								2W3
3A5	Duo Triode	T-5½	7BC	Fil.	1 4 2 8	0.22 0 11	Amplifier	90 135		2 5 20 0	3 7 30.0 Push-Pull Class C R F Amplifier		8 300	15	2,000	
3A8GT	Diode Triode Pentode	GT	8AS	Fil.	2 8 1 4	050 100	Det Amplifier Amplifier	90 90	0 90	0 0	0 2 1 5	0 0 5	0 2 Meg 0 8 Meg	325 250		1H5 and 1N5 1C3 and 1S5
3B5GT	Beam Amplifier	GT	7AQ	Fil.	1 4 2.8	0 10 0 05	Amplifier	45 67 5	45 67 5	4 5 7 0	4 4 6 7	0 3 0 5	8 000 5 000	1 400 1 500	70 180	
3B7/1291	Duo Triode	Lock-In	7BE	Fil.	2 8 1 4	110 220	Pwr Amplifier Oscillator	135 180	 . .	0 0	22 0 25 0	Class AB₂ Class C R F Pwr Amplifier 2800 Mw at 25 Mc 1400 Mw at 125 Mc		20	1,500	
								Characteristics Same as Type 6BY6								
3BY6	Heptode	T-5½	7CH	Cath	3 15	0 6	Sync Separator	250	100	2 5	6 5	9 0		1 900	EC3 = -2 5 V	
3C6/XXB	Duo Triode	Lock-In	7BW	Fil	1 4 2 8	0 10 0 05	Det Amplifier	90 90		0 0	4 5 3 2		11,200 12,800	14 5 14 1		3B7
3D6	Beam Power	Lock-In	6BB	Fil	1 4	0 220	Amplifier	150	90	4 5	9 9	1 0	14,000	2400	600	
3E5	Pentode	T-5½	6BX	Fil	1 4 2 8	050 025	Pwr. Amplifier Pwr Amplifier	67.5 90 67 5 90	67 5 90 67 5 90	5 0 8 0 5 0 8 0	5 0 6 0 4 5 5 5	1 0 1 5 1 0 1 5	120,000 140,000 110 000 120 000	1,300 1 200 1,200 1,100	100 200 90 175	3V4
3E6	Pentode	Lock-In	7CJ	Fil	1 4 2.8	0 1 050	R F Amplifier	90 90	90 90	0 0	4.2 2 9	1 7 1.2	25 Meg .325 Meg	2000 1700		
3LE4	Pentode	Lock-In	6BA	Fil.	2.8 1 4	0 05 0 10	Pwr Amplifier	90 90	90 90	9 0 9 0	9 0 10.0	1.8 2.0	110,000 100,000	1,600 1,750	300 325	3LF4, 3V4
3LF4	Beam Pentode	Lock-In	6BB	Fil.	1 4 2 8	0 10 0 05	Pwr Amplifier Pwr Amplifier	90 110 90 110	90 110 90 110	4 5 6 6 4 5 6 6	9.5 10 0 8 0 8.5	1.3 1 4 1.0 1 1	90,000♦ 100 000♦ 80,000♦ 110,000♦	2 200 2,200 2,000 2,000	270 400 230 330	3LE4, 3V4
3Q5GT, G	Beam Amplifier	T-9	7AP	Fil	1 4 2 8	0 10 0 05	Pwr Amplifier	Characteristics Same as Type 3LF4								3V4
4A6G	Duo Triode	ST-12	8L	Fil	2 0 4 0	0 12 0 06	Pwr Amplifier	90	. .	1.5	10.8	Class B Amp	P to P Load 8,000	20	1,000	
5AW4	Duo Diode	T-12	5T	Fil	5 0	4 0	F W Rectifier	450 Volts Per Plate RMS, 250 Ma Output Current with Cap Input to Filter, Peak Current = 750 Ma. Per Plate								5U4GB
5AX4GT	Duo Diode	GT	5T	Fil	5 0	2 5	F W Rectifier	350 V RMS Plate, 175 Ma D C Output, Cond Input 500 V RMS Plate 175 Ma. D C Output, Choke Input								
5AZ4	Duo Diode	Lock-In	5T	Fil	5 0	2 0	F W Rectifier	Characteristics Same as Type 5Y3GT								
5T4	Duo Diode	Metal	5T	Fil	5 0	2 0	F W Rectifier	450 V RMS Per Plate, 225 Ma. D C Output, Cond Input Filter 550 V RMS Per Plate, 225 Ma. D C Output Choke Input Filter								5U4G
5U4GA	Duo Diode	T-11	5T	Fil	5 0	3.0	F W. Rectifier	40 µf Cap Input—450 V RMS Per Plate, 250 Ma. Output, 460 V D C Output 10H Choke Input—550 V RMS Per Plate, 250 Ma. Output, 440 V D C Output								5U4GB
5W4, G, GT	Duo Diode	Metal, GT	5T	Fil	5 0	1.50	F W Rectifier	350 Volts RMS Per Plate, 110 Ma D C Output Current, Capacitor Input to Filter								5Y4G

TYPE	CLASS	CONSTRUCTION STYLE	CONSTRUCTION BASE DIAG.	EMITTER TYPE	EMITTER VOLTS	EMITTER AMP.	USE	PLATE VOLTS	SCREEN VOLTS	NEG GRID VOLTS	PLATE CUR-RENT MA.	SCREEN CUR-RENT MA.	PLATE ① RESISTANCE OHMS	AMP. ② FACTOR OR Gm µMHOS	POWER OUTPUT MW.	SUGGESTED REPLACEMENT TYPE
5 X3	Duodiode	ST-14	4C	Fil	5.0	2 0	Rectifier	400 V. Per Plate, RMS, 110 Ma. Output Current, Choke or Cond. Input to Filter 1275 V. Per Plate, RMS, 30 Ma. Output Current, Choke or Cond. Input to Filter								
5 X4G	Duo Diode	ST-16	5Q	Fil.	5 0	3.00	F W Rectifier	Characteristics Same as Type 5U4G								5U4G
5Z4	Duo Diode	Metal	5L	Fil.	5 0	2 0	F.W. Rectifier	350 V. RMS Plate, 125 Ma. D C Output, Cond Input 500 V RMS Plate, 125 Ma. D C Output Choke Input								
6A3	Triode	ST-16	4D	Fil.	6 3 6 3 6 3	1.00 1 00 1 00	Pwr. Amplifier	250 325 325	....'.	45 0 68 0 .	60 0 40.0‡ 40.0‡	Fixed Bias 850▲	2,500 3,000♦ 5,000♦	4 2	3,200 15,000 10,000	
6A4	Pentode	ST-14	5B	Fil.	6.3	0 30	Pwr. Amplifier	135 180	135 180	9.0 12.0	13.0 22.0	2 8 3.9	52,600 60,000	2,100 2,500	700 1,500	6K6GT
6A4/LA	Pentode	ST-14	5B	Fil.	6.3	0.30	Pwr. Amplifier	100 180	100 180	6.5 12 0	9.0 22.0	1 6 3 9	11,000 8,000	1,200 2,200	310 1,400	
6A5G	Triode	ST-16	6T	Cath.	6.3	1.25	Pwr. Amplifier	250	0	45	60	0	800	5,250	3750	
6A6	Duo Triode	ST-14	7B	Cath.	6.3 6.3 6.3	0.8 0.8 0.8	Pwr. Amplifier Driver Driver	300 250 294	 . .	0 5.0 6.0	35.0 6.0 7.0	Per Plate	8,000♦ 11,300 11,000	Max. Signal 35 35	10,000 .	6N7G
6AB5/6N5	Electron Ray	T-9	6R	Cath.	6.3	0.15	Indicator	135§ Series Plate Resistor 0 25 Meg , Target Current 2.0 Ma., Grid Bias = 10 for 0° Shadow								
6AB6G	Duo Triode	ST-12	7AU	Cath.	6 3	0 50	Pwr. Amplifier	250 250	Input Triode Output Triode	0 .	5 0 34.0	. . . .	. . . 8,000	. . . .	. 3,500	6N6G
6AB7/1853	Pentode	Metal	8N	Cath.	6.3	0.45	Amplifier	300	200	3 0	12 5	3 2	700,000	5,000		
6AC5GT, G	Triode	GT, ST-12	6Q	Cath.	6.3	0.40	Pwr. Amplifier	250	. .	0 0	5.0‡	(Class B, Two Tubes)			8,000	
6AD5GT	Triode	GT	6Q	Cath.	6.3	0 30	Amplifier	250		2 0	0.9		66,000	100		
6AD6G	Electron Ray	T-9	7AG	Cath.	6.3 6.3	0.15 0.15	Indicator	100§ Ray Control Volts = 45 for 0° Shadow, = -23 Volts for 135° Shadow 150§ Ray Control Volts = 75 for 0° Shadow, = -50 Volts for 135° Shadow								
6AD7G	Triode Pentode	ST-14	8AY	Cath.	6.3 6.3	0.85 0.85	Triode Amplifier Pentode Amp.	250 250	. 250	25 16.5	3.7 34.0	 6.5	19,000♦ 7,000	6 2,500	. 3,200	
6AE5GT, G	Triode	GT	6Q	Cath.	6.3	0.30	Amplifier	95		15	7.0		3,500	4.2		
6AE6G	Duo Plate Triode	ST-12,	7AH	Cath.	6.3 6.3 6.3 6.3	0.15 0.15 0.15 0.15	Remote Cut-Off Sharp Cut-Off	250 250 250 250	....	1.5 35.0 1 5 9.5	6.5 0.01 4.5 0.01	. . . .	25,000 35,000	25 . 33		
6AE7GT	Duo Triode	GT	7AX	Cath.	6.3	0.50	Amplifier	250 (Driver for P.P. 6AC5GT = 250 V. 10 Ma., 6AC5GT Plate Ma. = 76 Output 9.5 Watts with 10,000 Ohms Load)		13.5	5.0		9,300	14	Per Section	
6AF5G	Triode	ST-12	6Q	Cath.	6.3	0.30	Amplifier	180	. .	18.0	7.0		4,900	7.4	.	
6AF6G	Twin Electron Ray	T-9	7AG	Cath.	6.3	0.15	Indicator	100§ Ray Control Volts = 60♦ for 0° Shadow, ♦Zero Volts for 100° Shadow 135§ Ray Control Volts = 81♦ for 0° Shadow, ♦Zero Volts for 100° Shadow 250§ Ray Control Volts = 155♦ for 0° Shadow, ♦Zero Volts for 100° Shadow								
6AH5G	Beam Amplifier	ST-16	6AP	Cath.	6.3	0.90	Amplifier	350	250	18.0	54 0	2 5	4,200	5,200	10,800	6L6G

6AH7GT	Duo Triode	GT	8BE	Cath	6.3 6 3	0 30 0 30	Amplifier (Per Unit)	100 180		3 6 6 5	3 7 7 6		10 300 8 400	16 16		
6AJ4	Triode	T-6½	9B X	Cath	6 3	0 225	U H F Amplifier	125		68▲	16		4 200♦	42		
6AJ5	Pentode	T 5½	7BD	Cath	6 3	0 175	R F Amplifier	28	28	0 1	2 7	1 0	100 000	2 500		
6AL6G	Beam Amplifier	ST 16	6AM	Cath	6 3	0 90	Pwr Amplifier	Same as 6L6G								6L6G
6AM4	Triode	T-6½	9B X	Cath	6 3	0 225	U H F Amplifier	200		100▲	10		8 700♦	85		
6AN5	Pentode	T-5½	7BD	Cath	6 3	0 45	Pwr Amplifier	120	120	6 0	35 0	12 0	12 500♦	8 000	1,300	
6AQ7GT	Duodiode Triode	GT	8CK	Cath	6 3	0.30	Det Amplifier	250		2 0	2 3		44 000	70		
6AS6	Pentode	T-5½	7CM	Cath	6 3	175	R F Ampl fier	120	120	2	5 2	3 5	110 000	3200		
6A X6G	Duo Diode	ST 14	7Q	Cath	6 3	2 5	F W Rectifier	350 V RMS Plate 250 Ma D C Output Cond Input								
6B4G	Triode	ST 16	5S	Fil	6 3	1 0	Pwr Amplifier	Characteristics Same as Type 6A3								6A3
6B5	Duo Triode	ST 14	6AS	Cath	6 3	0 80	Pwr Amplifier	300 300	Input Triode Output Triode	0	8 0 45 0		7 000		4 000	
6B6G	Duodi Triode	ST 12	7V	Cath	6 3	0 30	Det Amplifier	250		20	0 9		91 000	100		6Q7GT
6B7 6B7S	Duodi Pentode	ST 12	7D	Cath	6 3 6 3	0 30 0 30	R F or I F Amplifier	100 250	100 125	3 0 3 0	5 8 9 0	1 7 2 3	300 000 600 000	950 1 125		
6B8 GT G	Duodi Pentode	Metal GT	8E	Cath	6 3	0 30	Det Amplifier	Characteristics Same as Type 6B7								
6BA7	Heptode	T-6½	8CT	Cath	6 3	300	Converter	250	100	1	3 8	10	1 0 Meg	950▼		
6BD5GT	Beam Amplifier	GT	6CK	Cath	6 3	0 90	TV Horizontal Amplifier	Max Peak Positive Pulse Plate Voltage = 4 000 V Max D C Cathode Current = 100 ma Max Plate Dissipation = 10 Watts Max Screen Dissipation = 3 0 Watts								6BQ6GTA
6BK6	Duodi Triode	T 5½	7BT	Cath	6.3	0 3	Det Ampl fier	250 100		2 0 1 0	1 2 0 5		62 500 80 000	100 100		
6BN7	Duo Triode with Different Triode Sections	T-6½	9AJ	Cath	6 3	0 75	Osc Triode 1 Amp Triode 2	120 250		1 0 15 0	5 0 24 0		14 000 2 200	28 12		
6BU5	Beam Pentode	T 12	8FP	Cath	6 3	0 15	TV H gh Voltage Regulator	20 000 20 000	70 70	3 4 2 4	0 5ε 1 0	υ 4				
6B Y6	Heptode	T 5½	7CH	Cath	6 3	0 3	Sync Separator	10	25	0	1 4	3 5	I_b = 50 μa When E_{c3} = 2 5 V			
6C6	Pentode	ST 12	6F	Cath	6 3 6 3 6 3 6 3	0 30 0 30 0 30 0 30	Ampl fier As Tr ode	100 250 180 250	100 100	3 0 3 0 5 3 8 0	2 0 2 0 5.3 6 5	0 50 0 50	1 Meg >1 Meg 11 000 10 000	1 185 1 225 20 20		77
6C7	Duodi Triode	ST 12	7G	Cath	6 3	0.30	Det Ampl fier	250		9 0	4 5		16 000	20		6SR7GT
6C8G	Duo Triode	ST 12	8G	Cath	6 3	0 30	Ampl fier Inv	250		4 5	3 2		22 500	36		
6D5G	Triode		6Q	Cath	6 3	0 70	Pwr Ampl fier	275		40	31		7 200	4 7	1 400	
6D6	Pentode	ST 12	6F	Cath	6 3 6 3	0 30 0 30	Ampl fier	100 250	100 100	3 0 3 0	8 0 8 2	2 2 2 0	<50 000♦ 800 000♦	1 500 1 600		78
6D7	Pentode	ST 12	7H	Cath	6 3	0 30	Amplifier	Same as 6C6								6C6
6D8G	Heptode	ST 12	8A	Cath	6.3 6 3	0 15 0 15	Converter	135 250	67 5 100	3 0 3 0	1 5 3 5	1 7 2 6	600 000 400 000	325▼ 550▼	G_2 = 135 V at 1 8 Ma G_2 = 250 V at 4 5 Ma●	7A8
6DB6	Pentode	T 5½	7CM	Cath	6 3	0 30	Color Demod	150	150	1 0	5 8	6 6	50 000	2 050 μmhos when E_{c3} = 3 V		

TYPE	CLASS	CONSTRUCTION STYLE	CONSTRUCTION BASE DIAG	EMITTER TYPE	EMITTER VOLTS	EMITTER AMP	USE	PLATE VOLTS	SCREEN VOLTS	NEG GRID VOLTS	PLATE CURRENT MA	SCREEN CURRENT MA	PLATE ① RESISTANCE OHMS	AMP ② FACTOR OR Gm μMHOS	POWER OUTPUT MW	SUGGESTED REPLACEMENT TYPE
6E5	Electron Ray	T-9	6R	Cath	6.3	0 30	Indicator	100§	(Series Plate Resistor 0 5 Megs Target Current 1 0 Ma. Grid Bias=3.3 for 90° Shadow)							6U5
								250§	(Series Plate Resistor 1 0 Meg Target Current 4 0 Ma. Grid Bias=8 0 for 90° Shadow)							
6E6	Duo Triode	ST-14	7B	Cath	6.3	0 60	Pwr Amplifier	180 250		20 0 27 5	11 5 18 0	•	15 000♦ 14 000♦	6 0 6 0	750 1 600	
6E7	Pentode	ST-12	7H	Cath	6 3	0.30	Amplifier	Same as 6D6								6D6
6F5 GT G	Triode	Metal GT ST-12	5M	Cath	6.3	0 3	Amplifier	100 250		1 0 2 0	0 4 0 9		85 000 66 000	100 100		
6F7 6F7S	Triode Pentode	ST-12	7E	Cath	6 3	0 30	Amplifier	100 250	(Tri) 100	3 0 3 0	3 5 6 5	1 5	16 200 850 000	8 5 1 100	(Pent)	
6F8G	Duo Triode	ST-12	8G	Cath	6.3	0 60	Amplifier Inv	250		8 0	9 0		7 700	20		6SN7GT
6G5/6H5	Electron Ray	T-9	6R	Cath	6.3	0.30	Indicator			0 to 22						6U5/6G5
6G6G	Pentode	ST-12	7S	Cath	6 3	0 15	Pwr Amplifier	135 180	135 180	6 0 9 0	11 5 15 0	2 0 2 5	170 000 175 000	2 100 2 300	600 1 100	6K6
6H4GT	Diode	GT	5AF	Cath	6.3	0 15	Rectifier	100			4 0					7A6
6H5	Electron Ray	T-9	6R	Cath	6.3	0.30	Indicator	Same as 6G5/6H5								6U5/6G5
6J4	Triode	T-5½	7BQ	Cath	6.3	0 4	Amplifier	150		200▲	15 0		4 500	55		
6J7G, GT	Pentode	Metal ST-12 GT	7R	Cath	6 3	0 30	R F Amplifier	100 250	100 100	3 0 3 0	2 0 2 0	0 5 0 5	1 0 Meg >1 0 Meg	1 185 1 225		6SJ7
6J8G	Triode Heptode	ST-12	8H	Cath	6 3	0 30	Mixer Osc	Characteristics Same as Type 7J7								
6K4	Triode	T-3	6K4	Cath	6.3	0 15	R F Amplifier	200		680▲	11 5		4 650	16		6AK4
6K5GT G	Triode	GT ST-12	5U	Cath	6 3	0.30	Amplifier	250		3 0	1 10		50 000	70		6F5
6K8, G GT	Triode Hexode	Metal ST-12 GT	8K	Cath	6 3	0.30	Mixer Oscillator	250 100 100	100 100 R_g=50 000 Ohms I_b=3 8 Ma G_m=3 000 μmhos (Triode Section Not Oscillating)	3 0 3 0	2 5 2 3	6 0 6 2	600,000 400,000	350▼ 325▼	(Hexode Section) (Hexode Section)	
6L5G	Triode	ST-12	6Q	Cath	6.3	150	Amplifier	250	0	9	8 0	0	9 000	1900		
6N4	Triode	T-5½	7CA	Cath	6.3	0 20	Amplifier	180		3 5	12 0		5 400♦	32		6C4
6E7	Pentode	ST-12	7H	Cath	6 3	0.30	Amplifier	Same as 6D6								6D6
6F5 GT G	Triode	Metal GT ST-12	5M	Cath.	6.3	0 3	Amplifier	100 250		1 0 2 0	0 4 0 9		85 000 66 000	100 100		
6F7 6F7S	Triode Pentode	ST-12	7E	Cath	6 3	0 30	Amplifier	100 250	(Tri) 100	3 0 3 0	3 5 6 5	1 5	16 200 850 000	8 5 1 100	(Pent)	
6F8G	Duo Triode	ST-12	8G	Cath	6 3	0 60	Amplifier Inv	250		8 0	9 0		7 700	20		6SN7GT
6G5/6H5	Electron Ray	T-9	6R	Cath	6 3	0.30	Indicator			0 to 22						6U5/6G5
6G6G	Pentode	ST-12	7S	Cath	6 3	0 15	Pwr Amplifier	135 180	135 180	6 0 9 0	11 5 15 0	2 0 2 5	170 000 175 000	2 100 2 300	600 1 100	6K6
6H4GT	Diode	GT	5AF	Cath	6 3	0 15	Rectifier	100			4 0					7A6
6H5	Electron Ray	T-9	6R	Cath	6.3	0 30	Indicator	Same as 6G5/6H5								6U5/6G5
6J4	Triode	T 5½	7BQ	Cath	6 3	0 4	Amplifier	150		200▲	15 0		4 500	55		

6J7G, GT	Pentode	Metal ST-12 GT	7R	Cath	6.3	0 30	R F Amplifier	100 250	100 100	3 0 3 0	2 0 2 0	0 5 0 5	1 0 Meg >1 0 Meg	1,185 1,225	. . . . .	6SJ7
6J8G	Triode Heptode	ST-12	8H	Cath	6.3	0 30	Mixer Osc	Characteristics Same as Type 7J7								
6K4	Triode	T-3	6K4	Cath	6.3	0 15	R F Amplifier	200		680▲	11 5		4,650	16		6AK4
6K5GT, G	Triode	GT, ST-12	5U	Cath	6 3	0.30	Amplifier	250		3 0	1 10	.	50,000	70	. . .	6F5
6K8, G, GT	Triode Hexode	Metal ST-12, GT	8K	Cath	6 3	0 30	Mixer Oscillator	250 100 100	100 100 R_g = 50 000 Ohms I_b = 3 8 Ma, G_m = 3,000 μmhos (Triode Section Not Oscillating)	3 0 3 0	2 5 2.3	6 0 6 2	600,000 400,000	350▼ 325▼	(Hexode Section) (Hexode Section)	
6L5G	Triode	ST-12	6Q	Cath	6.3	150	Amplifier	250	0	9	8 0	0	9,000	1900		
6N4	Triode	T-5½	7CA	Cath	6 3	0.20	Amplifier	180		3 5	12 0		5 400♦	32		6C4
6SK7, GT	Remote Cutoff Pentode	Metal GT	8N	Cath	6 3	0 30	R F Amplifier	100 250	100 100	1 0 3 0	13 0 9 2	4 0 2 6	120 000♦ 800 000♦	2 350 2 000		
6SR7GT	Duodi Triode	Metal GT	8Q	Cath	6 3	300	Det Ampl fier	250		9	9 5	. .	8 500	16		
6SS7	Remote Cutoff Pentode	Metal	8N	Cath	6 3	0 15	R F Amplifier	100 250	100 100	1 0 3 0	12 2 9 0	3 1 2 0	0 12 Meg♦ 1 0 Meg♦	1 930 1 850		6SG7GT
6ST7	Duodi Triode	Metal	8Q	Cath	6 3	15	Det Amplifier	250		9	9 5		8 500	16		
6SV7	Diode Pentode	Metal	7AZ	Cath	6 3 6.3	0 30 0 30	Det Amplifier	100 250	100 150	1 0 1 0	3 7 7 5	1 4 2 8	700 000 1 5 Meg	2 600 3 600		
6SZ7	Duodiode Triode	Metal	8Q	Cath	6 3	0 15	Amplifier	250		3 0	1 0		58 000	70		6SQ7GT
6T5	Electron Ray	ST-12	6R	Cath	6 3	0 30	Indicator	250§		0 22	3 0					6U5 6G5
6T7G	Duodiode Triode	ST-12	7V	Cath	6 3	0 15	Det Amplifier	100 250		1 5 3 0	0 3 1 2		95 000 62 000	65 65		
6T7G 6Q6G	Duodi Triode	ST-12	7V	Cath	6 3	0 15	Det Amplifier	250		3 0	1 2		62 000	65		6T7G
6U4GT	Diode	GT	4CG	Cath	6 3	1 2	H W Rectifier	350 A C Volts Per Plate RMS 125 Ma Output Current 335 V D C Output 20μf Cap Input								6W4GT
6U6GT	Beam Power	T-9	7S	Cath	6 3	75	Pwr Amplifier	200	135	14	55	3 0	3 000	6200	5 500	
6U7G	Remote Cutoff Pentode	ST-12	7R	Cath	6 3	0 30	R F Amplifier	100 250	100 100	3 0 3 0	8 0 8 2	[illegible] [illegible]0	250 000 800 000	1 500 1 600		6SK7GT,6K7GT
6V7G	Duodi Triode	ST-12	7V	Cath	6 3	0 3	Det Amplifier	Same Characteristics as Type 85								
6V8	Triple Diode Triode	T-6½	9AH	Cath	6 3	0 45	Det Amplifier	100 250		1 0 3 0	0 8 1 0	.	54 000 58 000	70 70		
6W5G	Duo Diode	ST 12	6S	Cath	6 3	0 90	F W Rectifier	325 V RMS Per Plate, 90 Ma D C Output Cond Input Filter 450 V RMS Per Plate, 90 Ma D C Output Choke Input Filter								6 X5G
6W7G	Pentode	ST-12	7R	Cath	6 3	150	R F Amplifier	250	100	3	2 0	0 5	1 Meg	1250		
6 Y3G	Diode	ST-12	4AC	Cath	6.3	0 70	H W Rectifier	5000 A C Volts Per Plate RMS 7 5 Ma Output Current								2 X2A
6 Y5	Duo Diode	ST-12	6J	Cath	6.3	0 80	F W Rectifier	350 V RMS Per Plate, 50 Ma D C Output								6 X5G
6 Y5V	Duo Diode	ST-12	6J	Cath	6.3	0 80	F W Rectifier	350 V RMS Per Plate, 60 Ma. D C Output								6 X5G
6 Y7G	Duo Triode	ST-12	8B	Cath	6.3	0 6	Class B Amp	Same Characteristics as Type 79								
6Z3	Diode		4G	Cath	6.3	0.30	H W Rectifier	350 V RMS Plate, 50 Ma. D C Output								1V
6Z4, 6Z4/84	Duo Diode	ST-12	5D	Cath	6.3	0 50	F W Rectifier	350 V RMS Per Plate, 60 Ma D C Output, Cond Input Filter								6 X5G
6Z5, 6Z5/12Z	Duo Diode	ST-12	6K	Cath.	6.3 12.6	0 80 0 40	F W Rectifier	230 V RMS Per Plate, 60 Ma. D C Output								6 X5G 14Y4
6Z7G	Duo Triode	ST-12	8B	Cath	6.3	0.3	Class B Amp	135 180		0 0	60 60	.	. . . .	9,000 12,000	2,500 4 200	
6Z Y5G	Duo Diode	ST-12	6S	Cath.	6.3	0.30	F W Rectifier	325 A C Volts Per Plate RMS 40 Ma, Output Current Capacitor Input to Filter								0Z4, 6 X5

TYPE	CLASS	CONSTRUCTION STYLE	CONSTRUCTION BASE DIAG	EMITTER TYPE	EMITTER VOLTS	EMITTER AMP	USE	PLATE VOLTS	SCREEN VOLTS	NEG GRID VOLTS	PLATE CURRENT MA.	SCREEN CURRENT MA	PLATE ① RESISTANCE OHMS	AMP ③ FACTOR OR Gm μMHOS	POWER OUTPUT MW	SUGGESTED REPLACEMENT TYPE
7A4	Triode	Lock In	5AC	Cath	6.3	0.30	Amplifier	90 250		0.0 8.0	10.0 9.0		6 700 7 700	20 20		
7A5	Beam Pentode	Lock In	6AA	Cath	6.3	0.75	Pwr Amplifier	110 125	110 125	7.5 190▲	40.0 44.0	3.0 3.3	16 000 17 000	5 800 6 000	1 500 2 200	
7AB7	Pentode	Lock In	8BO	Cath	6.3	0.15	Amplifier	250	100	2.0	4.0	1.3	500 000	1 800		
7AD7	Pentode	Lock In	8V	Cath	6.3	0.60	Video Amplifier	300 300	150 125	68▲ 68▲	28 25	7.0 6.0	300 000	9 500	(Class A_1 Amplifier) (Class A_1 Video Amplifier)	
7AF7	Duo Triode	Lock In	8AC	Cath	6.3	0.30	Amplifier	100 100 250		0 3.0 10	10.8‡ 5.0‡ 9.0‡		6 500 8 400 7 600	17 16 16	 R_k = 600 Ohms R_k = 1 100 Ohms	
7AH7	Semi Remote Pentode	Lock In	8V	Cath	6.3	0.15	R F Amplifier	250	250	250▲	6.8	1.9	1.0 Meg	3 300		
7AJ7	Pentode	Lock In	8V	Cath	6.3	3	R F Amplifier	250	100	3	2.2	0.7	1 Meg	1 575		
7B4	Triode	Lock In	5AC	Cath	6.3	0.30	Amplifier	100 250		1.0 2.0	0.4 0.9		85 000 66 000	100 100		
7B5	Pentode	Lock In	6AE	Cath	6.3	0.40	Pwr Amplifier	100 250 315	100 250 250	7.0 18.0 21.0	9.0 32.0 25.5	1.6 5.5 4.0	104 000 68 000 75 000	1 500 2 300 2 100	350 3 400 4 500	6K6GT
7C4	H F Diode	Lock In	4AH	Cath	6.3	0.15	Detector	117 V RMS			5.0	Resonant Frequency 900 Mc				
7E5	Triode	Lock In	8BN	Cath	6.3	15	Amp Oscillator	180		3	5.5		12 Meg	36		
7E6	Duo Diode Triode	Lock In	8W	Cath	6.3	0.30	Det Amplifier	250 100		9.0 3.0	9.5 3.9		8 500 11 000	16 16.5		
7E7	Duo Diode Pentode	Lock In	8AE	Cath	6.3	0.30	Det Amplifier	100 250	100 100	1.0 3.0	10.0 7.5	2.7 1.6	150 000♦ 700 000♦	1 600 1 300		
7G7	Pentode	Lock In	8V	Cath	6.3	0.45	R F Amplifier	250	100	2.0	6.0	2.0	800 000♦	4 500		
7G8	Duo Tetrode	Lock In	8BV	Cath	6.3	3	Amplifier	250	100	2.5	4.5‡	0.8‡	225 Meg	2 100		
7H7	Semi Remote Pentode	Lock In	8V	Cath	6.3	0.30	R F Amplifier	100 250	100 150	1.5 180▲	7.5 10.0	2.6 3.2	350 000♦ 800 000♦	4 000 4 000		
7J7	Triode Heptode	Lock In	8BL	Cath	6.3	0.30	Mixer Oscillator	100 250 100 250■	100 100 (R_1 50 000) (R_1 −50 000)	3.0 3.0	1.5 1.4 3.2 5.0	2.6 2.8 (Triode Grid Current 0.3 Ma) (Triode Grid Current 0.4 Ma)	500 000 1.5 Meg	280▼ 290▼	(Heptode) (Heptode) (Triode) (Triode)	
7K7	Duo Diode Triode	Lock In	8BF	Cath	6.3	0.30	Det Amplifier	250		2.0	2.3		44 000	70		
7L7	Pentode	Lock In	8V	Cath	6.3	0.30	R F Amplifier	100 250	100 100	1.0 1.5	5.5 4.5	2.4 1.5	100 000♦ 1.0 Meg♦	3 000 3 100	R_k 125 R_k 250	
7R7	Duo Diode Pentode	Lock In	8AE	Cath	6.3	0.3	Detector R F Amplifier	100 100 250 250	100 100 100 100	2.0 1.0 2.0 1.0	3.4 5.5 3.5 6.2	1.0 2.2 1.0 1.6	500 000♦ 350 000♦ 1 800 000♦ 1 000 000♦	2 100 3 000 2 200 3 200		
7S7	Triode Heptode	Lock In	8BL	Cath	6.3	0.30	Mixer Oscillator	100 250 100 250■	100 100 R_{g1} −50 000 R_{g1} −50 000	2.0 2.0	1.9 1.8 3.0 5.0	3.0 3.0 (Triode Grid Current = 0.3 Ma) (Triode Grid Current − 0.4 Ma)	500 000♦ 1.25 Meg♦	500▼ 525▼	(Heptode) (Heptode) (Triode) (Triode)	
7T7	Pentode	Lock In	8V	Cath	6.3 6.3	0.30 0.30	Amplifier	100 250	100 150	1.0 1.0	5.3 10.8	2.1 4.1	350 000 900 000	4 000 4 900		

7V7	Pentode	Lock-In	8V	Cath.	6.3	0.45	R F Amplifier	300	150	160▲	10.0	3.9	300,000	5,800	.....	
7W7	Pentode	Lock-In	8BJ	Cath.	6.3	0.45	R F Amplifier	Characteristics Same as Type 7V7.								
7 X6	Duo Diode	Lock-In	7D X	Cath.	6.3	1.2	Rectifier Doubler	235 Volts Per Plate RMS, 75 Ma. D C Output Per Plate (H.W. Rectifier) 117 Volts Per Plate RMS, 75 Ma. D C Output (Voltage Doubler)								
7 X7/ X XFM	Duo Diode Triode	Lock-In	8BZ	Cath.	6.3	0.30	Det. Amplifier	100 250	....	0 1.0	1.2 1.9	....	85,000 67,000	85 100	....	
7Z4	Duo Diode	Lock-In	5AB	Cath.	6.3	0.90	F.W. Rectifier	325 A C Volts Per Plate RMS, 100 Ma. Output Current, Capacitor Input to Filter 450 A C Volts Per Plate RMS, 100 Ma. Output Current. Choke Input to Filter 6 Henrys Min.								
10	Triode	ST-16	4D	Fil.	7.5	1.25	Pwr. Amplifier	250 350 425	....	23.5 32.0 40.0	10.0 16.0 18.0	....	13,000 11,000 10,200	8.0 8.0 8.0	400 900 1,600	
12A, 112A	Triode	ST-14	4D	Fil.	5.0	0.25	Det. Amplifier	90 135	....	4.5 9.0	5.0 6.2	....	5,400 5,100	8.5 8.5	35 130	
12A4	Triode	T-6½	9AG	Cath.	6.3 12.6	0.60 0.30	Amplifier	250	...	9.0	23	....	2,500	20	.....	
12A5	Pentode	ST-12	7F	Cath.	12.6 6.3	0.30 0.60	Pwr. Amplifier	100 180	100 180	15.0 25.0	19.0 48.0	6.0 14.0	4,500 3,300	1,700 2,400	800 3,400	
12A6	Beam Amplifier	Metal	7S	Cath.	12.6	0.15	Pwr. Amplifier	250	250	12.5	30	3.5	7,500	3,000	3,400	
12A6GT	Beam Amplifier	T-9	7S	Cath.	12.6	0.15	Pwr. Amplifier	Same as 12A6								
12A7	Diode Pentode	ST-12	7K	Cath.	12.6	0.30	Rectifier Amplifier	125 V. RMS Plate, 30 Ma. D C Output (Rect.) 135	 135	 13.5	 9.0	 2.5	 13,500	 975	 550	
12AH7GT	Duo Triode	GT	8BE	Cath.	12.6	0.15	Amplifier	100 180	....	3.6 6.5	3.7 7.6	....	10,300 8,400	16 16	....	
12AW6	Pentode	T-5½	7CM	Cath.	12.6	0.15	R F Amplifier	250 125 100	150 125 100	200▲ 100▲ 100▲	7 0 7.2 5.5	2.0 2.1 1.6	0.8 Meg. 0.5 Meg. 0.3 Meg.	5,000 5,100 4,750	....	12AU6
12B7	Pentode	Lock-In	8V	Cath.	12.6	0.15	Amplifier	Same as Lock In Type 14A7								14A7
12B8GT	Triode Pentode	GT	8T	Cath.	12.6	0.30	Triode Amplifier Pentode Amp.	90 90	.. 90	0.0 3.0	2.8 7.0	... 2.0	37,000 200,000	90 1,800	....	6AT6 6BA6
12BA7	Heptode	T-6½	8CT	Cath.	12.6	0.15	Converter	100	100	1.0	3.6	10.2	500,000	900♥	.....	
12C8	Duodi Pentode	Metal	8E	Cath.	12.6	0.15	Det. Amplifier	See Type 6B8								
12ED5	Pentode	T-5½	7CV	Cath.	12.6	0.45	Pwr Amplifier	110 125	4 0 4.5	110 125	32 37	4 7	4,500 4,500	8,100 8.500	1,100 1.500	12ED5
12F5GT	Triode	T-9	5M	Cath.	12.6	0.15	Amplifier	250	..	2	0.9	...	66,000	100	.	
12G4	Triode	T-5½	6BG	Cath.	12.6	0.15	Amplifier	Same as One Section of Type 6SN7GTA								
12H4	Triode	T-5½	7DW	Cath.	6 3 12.6	0.3 0.15	Amplifier	Same as One Section of Type 6SN7GTA								
12J7GT, G	Pentode	GT, ST-12	7R	Cath.	12.6	0.15	R F Amplifier	Characteristics Same as Type 6J7 250	 100	 3	 2.0	0 5	1.0 Meg. >	1,225	.....	
12K8, GT	Triode Hexode	Metal, GT	8K	Cath.	12.6	0.15	Mixer Oscillator	Characteristics Same as Type 6K8GT 250	 100	 3	 2.5	6.0	600,000	350♥	Hexode Section	
12L8GT	Duo Pentode	GT	8BU	Cath.	12.6	0.15	Pwr. Amplifier	110 180	110 180	5.5 9.0	6.1‡ 13.0‡	1.3‡ 2.8	14,000‡ 10,000‡	1,680‡ 2,150‡	300‡ 1,000‡	
12Q7GT, G	Duo Diode Triode	GT, ST-12	7V	Cath.	12.6	0.15	Det. Amplifier	Characteristics Same as Type 6Q7GT 250		 3	 1.1	....	58,000	70	.....	
12SF5, GT	Triode	T-9	6AB	Cath.	12.6	.150	Amplifier	250	...	2.0	0.9	....	66,000	100	.....	
12SR7	Duo Diode Triode	Metal	8Q	Cath.	12.6	0.15	Det. Amplifier	Characteristics Same as Type 6SR7GT 250		 9	 9.5	....	8,500	16	.....	
12Z3	Diode	ST-12	4G	Cath.	12.6	0.30	H.W. Rectifier	235 V. RMS Per Plate, 55 Ma. D C Output, Condenser Input Filter								

TYPE	CLASS	CONSTRUCTION STYLE	BASE DIAG	EMITTER TYPE	VOLTS	AMP	USE	PLATE VOLTS	SCREEN VOLTS	NEG GRID VOLTS	PLATE CUR RENT MA	SCREEN CUR RENT MA	PLATE ① RESISTANCE OHMS	AMP ③ FACTOR OR Gm µMHOS	POWER OUTPUT MW	SUGGESTED REPLACEMENT TYPE
12Z5	Duo Diode		7L	Cath	12 6	0 30	Rect Doub	225 V RMS Per Plate 60 Ma D C Output Condenser Input Filter								6Z5/12Z5
14A4	Triode	Lock In	5AC	Cath	12 6	150	Amplifier	250		8	9		7 700♦	20		
14A5	Beam Power	Lock In	6AA	Cath	12 6	150	Pwr Amplifier	250	250	12 5	30	3 5	7 500	3 000	2 800	
14AF7/XXD	Duo Triode	Lock In	8AC	Cath	12 6	0 15	Amplifier	Characteristics Same as Type 7AF7 250		10	9		7 600	16		
14C7	Pentode	Lock In	8V	Cath	12 6	0 15	R F Amplifier	100 250	100 100	1 0 3 0	5 7 2 2	1 8 0 7	400 000♦ 1 0 Meg♦	2 275 1 575		
14E6	Duodi Triode	Lock In	8W	Cath	12 6	150	Det Amplifier	250		9 0	9 5		8 500	16		
14E7	Duo Diode Pentode	Lock In	8AE	Cath	12 6	0 15	Det Amplifier	Characteristics Same as Type 7E7 250	100	3	7 5	1 6	700 000	1 300		
14H7	Semi-Remote Pentode	Lock-In	8V	Cath	12 6	0 15	R F Amplifier	Characteristics Same as Type 7H7 100	100	1 5	7 5	2 6	350 000	4 000		
14J7	Triode Heptode	Lock-In	8BL	Cath	12 6	0 15	Mixer Oscillator	Characteristics Same as Type 7J7 250		8	9		7 700	2 600		
14R7	Duo Diode Pentode	Lock-In	8AE	Cath	12 6	0 15	Det Amplifier	Characteristics Same as Type 7R7 100	100	1 0	5 5	2 2	350 000	3 000		
14S7	Triode Heptode	Lock In	8BL	Cath	12 6	0 15	Mixer Oscillator	100	100	2	1 9	3 0	500 000	500♥		
14W7	Pentode	Lock In	8BJ	Cath	12 6	225	R F Amplifier	300	300		10 0	3 9	0 3 Meg	5 800		
14X7	Duodi Triode	Lock In	8BZ	Cath	12 6	150	Det Amplifier	250		1 0	1 9		67 000	100		
14Z3	Diode		4G	Cath	14 0	0 30	H W Rectifier	250 V RMS Plate 60 Ma D C Output								12Z3
15	Pentode	ST 12	5F	Cath	2 0	0 22	Amplifier	135	67 5	1 5	1 85	0 3	800 000	750		
16 16B	Diode		4B	Fil	7 5		H W Rectifier									81
18	Pentode	ST 14	6B	Cath	14 0	0 30	Pwr Amplifier	See Type 6F6G								
19	Duo Triode	ST 12 GT	6C	Fil	2 0 2 0 2 0	0 26	Pwr Amplifier	135 135 135	•	0 3 0 6 0	10 0 3 4 0 2		10 000♦ 10 000♦ 10 000♦		2 100 1 900 1 600	
19C8	3 Diode Triode	T-6½	9E	Cath	18 9	0 15	Det Amplifier	100		1 0	0 5		80 000	100		
19V8	Triple Diode Triode	T 6½	9AH	Cath	18 9	0 15	Det Amplifier	Characteristics Same as Type 6V8 250		3 0	1 0		58 000	70		
20	Triode	T 8	4D	Fil	3 3	0 132	Pwr Amplifier	90 135		16 5 22 5	2 8 6 0		9 600 6 500	3 5 3 5	50 130	
22	Tetrode	ST 14	4K	Fil	3 3	0 132	Amplifier	135	67 5	1 5	3 7	1 3	250 000	500		
24A, 24S	Tetrode	ST 14	5E	Cath	2 5 2 5	1 75 1 75	R F Amplifier	180 250	90 90	3 0 3 0	4 0 4 0	1 7 1 7	400 000 600 000	1 000 1 050		
25, 25S	Duodi Triode		6M	Fil	2 0	0 06	Det Amplifier	135		3 0	1 0			20		1B5 25S
25A6, G, GT	Pentode	Metal ST 14 GT	7S	Cath	25 0	0 30	Pwr Amplifier	95 135 160	95 135 120	15 0 20 0 18 0	20 0 37 0 33 0	4 0 8 0 6 5	45 000 35 000 42 000	2 000 2 450 2 375	900 2 000 2 200	
25A7GT	Diode Pentode	GT	8F	Cath	25 0 25 0	0 30 0 30	H W Rectifier Pwr Amplifier	117 A C Volts Per Plate RMS 75 Ma Output Current 100	100	15 0	20 5	4 0	4 500	1 800	770	
25AC5GT	Triode	GT	6Q	Cath	25 0 25 0	0 30 0 30	Pwr Amplifier Dyn Coupled Amplifier	110 165	Bias from 6AE5GT Driver	+ 15	45 0 46 0		15 200 2 000	58	2 000	

25B5	Duo Triode	ST-12	6D	Cath.	25.0	0.30	Pwr. Amplifier	See Type 25N6G								
25B6G	Pentode	ST-14	7S	Cath.	25.0	0.30	Pwr. Amplifier	105 200	105 135	16 0 23 0	48 0 62.0	2.0 1.8	1,700 2,500	4,800 5,000	2,400 7,100	25A6GT
25B8	Triode Pentode	T-9	8T	Cath.	25	0.15	Triode Amplifier Pentode Amp	100 100	. . . 100	1 0 3.0	0.6 7 6	. 2.0	75,000 185,000	112 370	....	
25C6G	Beam Power	ST-14	7S	Cath.	25.0	0.30	Amplifier	200	135	14.0	61	2.2	2,600	7,100	6,000	
25D8GT	Diode Triode Pentode	.....	8AF	Cath.	25.0	0.15	Det. Amplifier	100 100	. . 100	1.0 3 0	.5 8.5	. . . 2.7	.....	100 1,900	(Triode) (Pentode)	12AV6 and 12BD6
25N6G	Duo Triode	ST-12	7W	Cath.	25.0	0.30	Pwr. Amplifier	110 180	110* 100*	0 0	45 46	7.0* 5 8*	2,000 4,000	....	2,000 3,800	
25Y5	Duo Diode	ST-12	6E	Cath.	25.0	0.30	Rect. Doubler	117 V. RMS Per Plate, 75 Ma. D C Output. Per Plate 235 V RMS Plate, 75 Ma. D C Output Per Plate								25Z5
26	Triode	ST-14	4D	Fil.	1.5	1.05	Amplifier	90 180	.... . .	7 0 14.5	2.9 6.2	....	8,900 7,300	8.3 8 3	....	
26A6	Pentode	I-5½	7BK	Cath.	26.5	0.07	R F Amplifier	26.5 250	26 5 250	....	1.7 10.5	0.7 4.0	250,000 1,000,000	.....	....	
26A7	Duo Pentode	T-9	8BU	Cath.	26.5	0.6	Pwr. Amplifier	26.5	26.5	4 5	20	2.0	1,500	5,500‡	200	
26C6	Duodi. Triode	T-5½	7BT	Cath.	26.5	0.07	Det. Amplifier	Same Characteristics as Type 7E6								
26D6	Heptode	T-5½	7CH	Cath.	26.5	0.07	Converter	26.5 100 250	26.5 100 100	0.5 1.5 1.5	0.45 2.8 3.0	1.6 8.0 7.8	.. 500,000 1,000,000	270 455 475	....	
27, 27S	Triode	ST-12	5A	Cath.	2.5 2.5 2.5 2.5 2.5	1.75 1.75 1.75 1.75 1.75	Amplifier Detector	90 135 180 250 250	....	6.0 9.0 13.5 21.0 30.0♦	3.0 4.7 5.0 5.2 Adjust Bias for 0.2 Ma. Plate Current Without Signal	....	10,000 9,000 9,000 9,250	9.0 9.0 9.0 9.0	....	
28Z5	Double Diode	Lock-In	6BJ	Cath.	28.0 28.0	0.24 0.24	F.W. Rectifier	325 450	A C Volts Per Plate, RMS, 100 Ma. Output Current, Condenser Input to Filter A C Volts Per Plate, RMS, 100 Ma. Output Current, 6h Choke Input to Filter							
30	Triode	ST-12	4D	Fil.	2.0 2.0 2.0	0.06 0.06 0.06	Amplifier	90 135 180	....	4.5 9.0 13.5	2.5 3.0 3.1	....	11,000 10,300 10,300	9.3 9.3 9.3	....	
31	Triode	ST-12	4D	Fil.	2.0 2.0	0.13 0.13	Pwr. Amplifier	135 180	. . . . .	22.5 30.0	8.0 12.3	. . . . . .	7,000 5,700	3.8 3.8	185 375	
32	Tetrode	ST-14	4K	Fil. . . .	2.0 2.0 2.0	0.06 0.06 0.06	R F Amplifier Detector	135 180 180	67.5 67.5 67.5	3.0 3.0 6.0♦	1.7 1.7 Adjust Bias for 0.2 Ma. Plate Current Without Signal	0.4 0.4	950,000 1.2 Meg.	640 650	....	
32L7GT	Diode Beam Amplifier	GT	8Z	Cath.	32.5 32.5	0.30 0.30	Rectifier Pwr. Amplifier	125 RMS Volts Per Plate, 60 Ma. Output Current. Condenser Input to Filter 110	 110	 7.5	 40.0	 3.0	 2,600	 6,000	 1,000	
33	Pentode	ST-14	5K	Fil.	2.0 2.0	0.26 0.26	Pwr. Amplifier	135 180	135 180	13.5 18.0	14.5 22.0	3.0 5.0	7,000 6,000	1,450 1,700	700 1,400	
34	Pentode	ST-14	4M	Fil.	2.0 2.0 2.0	0.06 0.06 0.06	R F Amplifier	67.5 135 180	67.5 67.5 67.5	3.0 3.0 3.0	2.7 2.8 2.8	1.1 1.0 1.0	400,000 -600,000 1 Meg.	560 600 620	....	
35, 51, 35S 51S	Tetrode	ST-14	5E	Cath.	2.5 2.5	1.75 1.75	R F Amplifier	180 250	90 90	3.0 3.0	6.3 6.5	2.5 2.5	300,000 400,000	1,020 1,050	....	
35Z6G	Duo Diode	ST-14	7Q	Cath.	35.0	0.30	Doub. Rectifier	117 V. RMS Plate, 110 Ma. D C Output								
36, 36A	Tetrode	ST-12	5E	Cath. . .	6.3 6.3 6.3 6.3 6.3	0.30 0.30 0.30 0.30 0.30	R F Amplifier Detector	100 135 180 250 250	55 67.5 90 90 20 to 25	1.5 1.5 3.0 3.0 6.0♦	1.8 2.8 3.1 3.2 Adjust Bias for .1 Ma. Plate Current Without Signal	Not over 1/3 Plate Cur.	550,000 475,000 500,000 550,000	850 1,000 1,050 1,080	....	

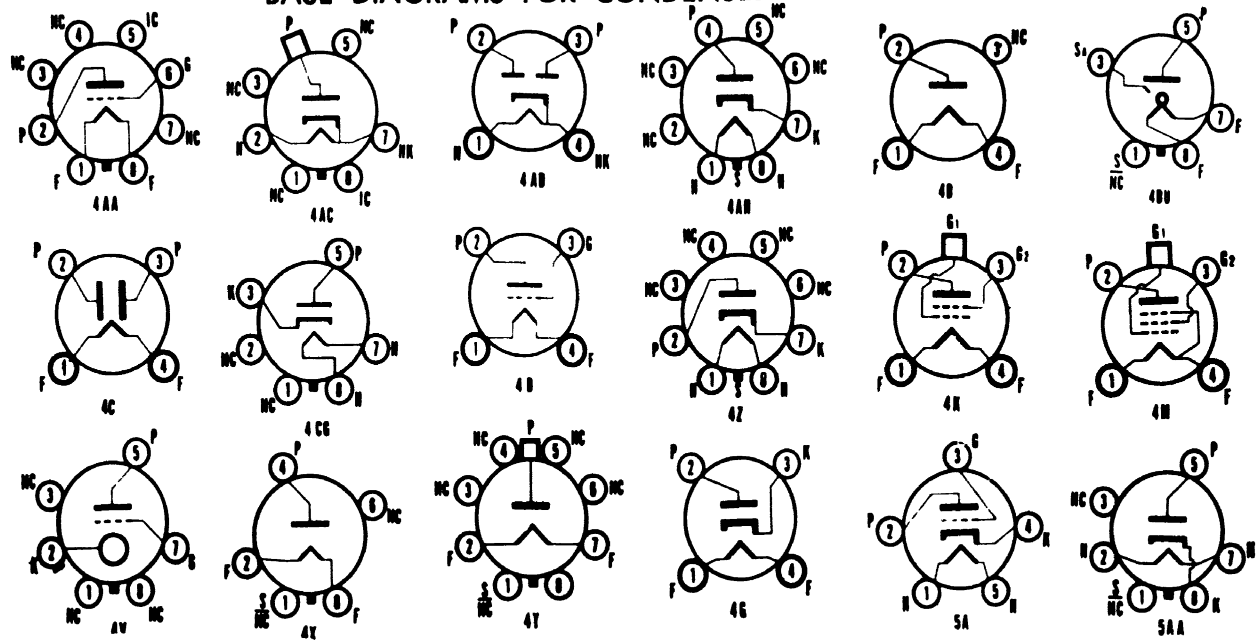
TYPE	CLASS	CONSTRUCTION STYLE	CONSTRUCTION BASE DIAG	EMITTER TYPE	EMITTER VOLTS	EMITTER AMP	USE	PLATE VOLTS	SCREEN VOLTS	NEG GRID VOLTS	PLATE CUR RENT MA	SCREEN CUR RENT MA	PLATE ① RESISTANCE OHMS	AMP ② FACTOR OR Gm μMHOS	POWER OUTPUT MW	SUGGESTED REPLACEMENT TYPE
37, 37A	Triode	ST-12	5A	Cath	6 3 6 3 6 3 6.3	0.30 0 30 0 30 0 30	Amplifier	90 135 180 250		6 0 9 0 13 5 18 0	2 5 4 1 4 3 7 5		11,500 10,000 10,200 8 400	9 2 9 2 9 2 9 2	.	
38, 38A	Pentode	ST-12	5F	Cath	6 3 6 3 6 3 6.3	0 30 0 30 0 30 0.30	Pwr Amplifier	100 135 180 250	100 135 180 250	9 0 13 5 18 0 25 0	7 0 9 0 14 0 22 0	1 2 1 5 2 4 3 8	15,000 13,500 11,600 10 000	875 925 1 050 1,200	270 550 1,000 2,500	
39, 39 44, 39A	Pentode	ST-12	5F	Cath	6 3 6 3 6.3	0 30 0 30 0.30	R F Amplifier	90 180 250	90 90 90	3 0 3 0 3 0	5 6 5 8 5 8	1 6 1 4 1 4	375,000 750 000 1 Meg	960 1 000 1 050		
40	Triode	ST-14	4D	Fil	5 0	0 25	Amplifier	135		1 5	0 2		150 000	30		
40A1	Ballast	T-9	8ES				Regulator	Avg Operating Current—74 Ma at 20 Volts 150 Ma at 40 Volts, 155 Ma. at 60 Volts								
40B2	Ballast	T-9	8ES				Regulator	Avg. Operating Current— 140 Ma at 20 Volts 150 Ma at 40 Volts, 155 Ma. at 60 Volts								
40Z5 45Z5GT	Diode	GT	6AD	Cath	45	0 15	H W Rectifier	Characteristics Same as Type 35Y4								
41	Pentode	ST-12	6B	Cath	6 3	0 40	Pwr Amplifier	Characteristics Same as Type 6K6GT and 7B5								
42	Pentode	ST-14	6B	Cath	6 3	0 65	Pwr Amplifier	Characteristics Same as Type 6F6G								
43	Pentode	ST-14	6B	Cath	25 0	0.30	Pwr Amplifier	Characteristics Same as Type 25A6GT								
44	Pentode		5F	Cath	6 3	0.30	Amplifier	See Type 39 or 39 44								39/44
45	Triode	ST-14	4D	Fil	2 5 2 5 2 5	1 5 1 5 1 5	Pwr Amplifier	180 250 275		31 5 50 0 56 0	31 0 34 0 3o 0		2,700 3,900 4 600	3 5 3 5 3 5	830 1,600 2,000	
45A	Triode		4D	Fil	2 5	1 50	Pwr Amplifier	325		68	43		3,200	3 5	3,000	45
45Z3	Diode	T-5½	5AM	Cath	45 0	0 075	H W Rectifier	117 A C Volts Per Plate RMS, 65 Ma Output Current, Min Supply Impedance = 15 Ohms								
46	Dual Grid Triode	ST-16	5C	Fil	2 5 2 5 2 5	1 75 1 75 1 75	Pwr Amplifier (Class B) (Class B)	250 300 400	Tie Gs to P Tie Gs to G Tie Gs to G	33 0 0 0	22 0 150 Peak Per Tube 200 Peak Per Tube		6,400 5,200♦ 5,800♦	5 6 2 Tubes 2 Tubes	1,250 16,000 20,000	
47	Pentode	ST-16	5B	Fil	2 5	1 75	Pwr Amplifier	250	250	16 5	31 0	6 0	7 000	2 500	2,700	2A5
48	Tetrode	ST-16	6A	Cath	30	0 40	Pwr. Amplifier	95 125	95 100	20 0 22 5	52 52	12 0 12 0	1,500 1,500	3 900 3,900	2,000 3,000	
49	Dual Grid Triode	ST-14	5C	Fil	2 0	0 12	Class A Amp Class B Amp	135 180	Gs to P Gs to G	20 0	6 0 4 0	 2 Tubes	11,000 12,000♦	4 7	170 3,500	
50	Triode	ST-16	4D	Fil	7 5 7 5 7 5 7 5	1 25 1 25 1 25 1 25	Pwr. Amplifier	300 350 400 450		54 0 63 0 70 0 84 0	35 0 45 0 55 0 55 0		4,600 4,100 3 670 4,350	3 8 3 8 3 8 3 8	1,600 2,400 3,400 4,600	
50A1	Ballast	T-6½	9CM				Fil Ballast	Avg Operating Current—52 Ma at 30 Volts 54 Ma at 50 Volts, 56 Ma at 65 Volts								
50A X6G	Duo Diode	ST-14	7Q	Cath	50 0	0 30	F W Rectifier	Characteristics Same as Type 6AX6G								
50BM8	Triode Pentode	T-6½	9EX	Cath	50	0 100	A F Voltage and Pwr Amp	100 100	0 6	 100	3 5 26	 5	28 000 5 600	2 500 6 400	 1 050	
50C6G	Beam Amplifier	ST-14	7S	Cath	50 0	0 15	Pwr Amplifier	135 200	135 135	13 5 14 0	58 0 61 0	3 5 2 2	9,300 18 300	7,000 7 100	3,600 6,000	

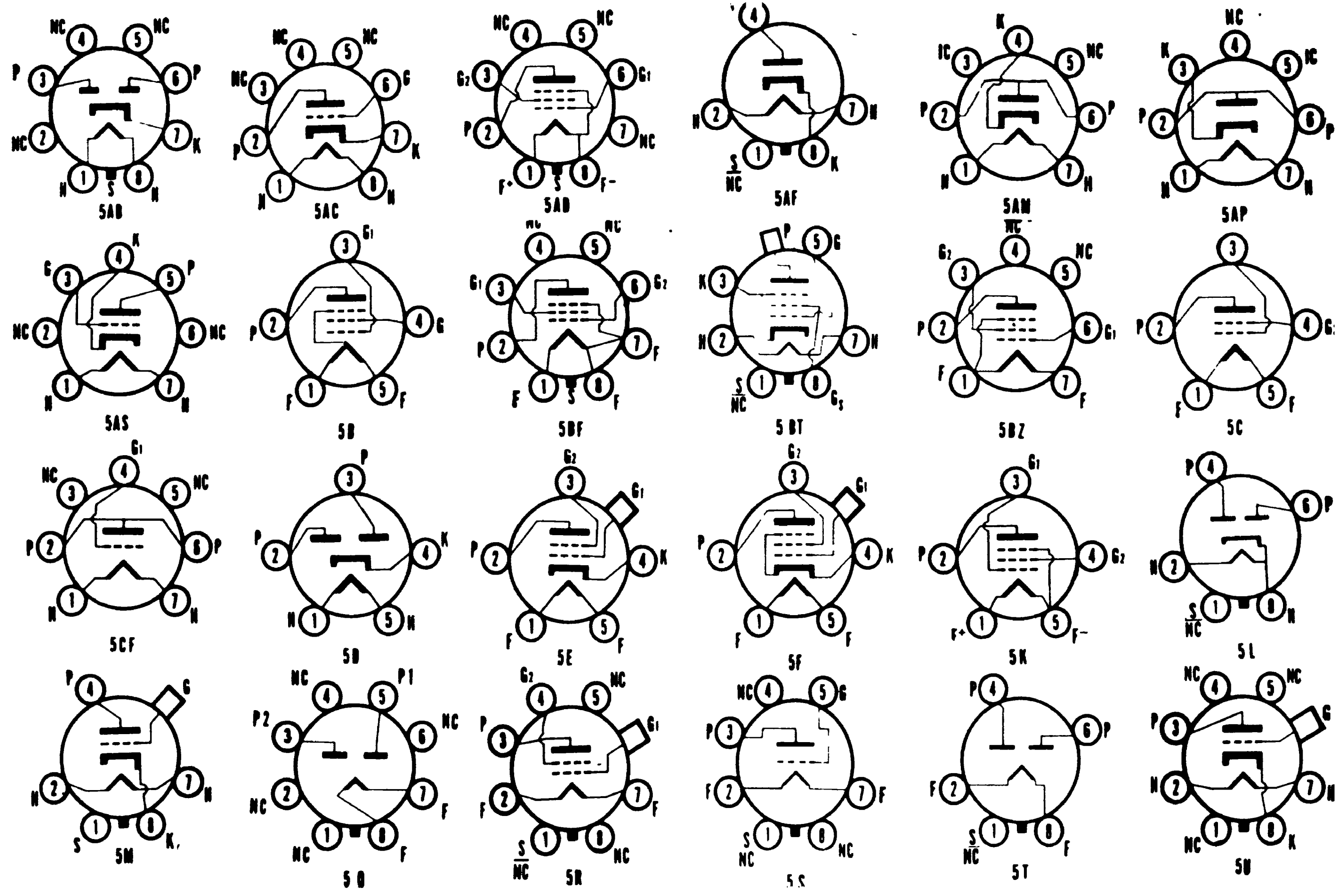
50Y6GT	Duo Diode	GT	7Q	Cath.	50.0	0.15	F.W. Rectifier	Characteristics Same as Type 25Z6GT								
50Z7G	Duo Diode	ST-12	8AN	Cath.	50	0.15	F.W. Rectifier	117 V. RMS Per Plate, 65 Ma. D C Output								
51, 51S	Tetrode	ST-14	5E	Cath.	2.5	1.75	Amplifier	See Type 35, 35 51								35
52	Dual Grid Triode	ST-14	5C	Fil. .	6.3	0.30	Class A Amp. Class B Amp.	110 180	. 2 Tube	0 0	43 3.0		2,000 10,000	5.2	1,500 5,000	6A4/LA
53	Duo Triode	ST-14	7B	Cath.	2.5	2.0	Pwr. Amplifier	Characteristics Same as Type 6N7GT								
55	Duodi Triode	ST-12	6G	Cath.	2.5	1.0	Det. Amplifier	Characteristics Same as Type 6V7G								
55S	Duodi Triode	ST-12	6G	Cath.	2.5	1.00	Det. Amplifier	250		20	8.0		7,500	8.3	350	55
56, 56S	Triode	ST-12	5A	Cath.	2.5 2.5	1.0 1.0	Amplifier Detector	250 250	.	13.5 20.0♦	5.0 Adjust Bias for 0.2 Ma. Plate Current Without Signal		9,500	13.8		
56AS	Triode	ST-12	5A	Cath.	6.3	0.40	Amplifier	250		13.5	5.0		9,500	13.8		76
57, 57S	Pentode	ST-12	6F	Cath.	2.5 2.5 2.5	1.0 1.0 1.0	Amplifier Detector	100 250 250†	100 100 100	3.0 3.0 4.3♦	2.0 2.0 Adjust Bias for 0.1 Ma. Plate Current Without Signal	0.5 0.5	1 Meg. 1 Meg.	1,185 1,225	. . . .	
57AS	Pentode	ST-12	6F	Cath.	6.3	0.40	Amplifier	250	100	3.0	2.0	0.5	1 Meg.	1,225		6C6
58, 58S	Pentode	ST-12	6F	Cath.	2.5 2.5	1.0 1.0	Amplifier	100 250	100 100	3.0 3.0	8.0 8.2	2.2 2.0	250,000 800,000	1,500 1,600	. . . .	
58AS	Pentode	ST-12	6F	Cath.	6.3	0.40	Amplifier	250	100	3.0	8.2	2.0	800,000	1,600	.	6D6,78
59	Pentode	ST-16	7A	Cath.	2.5 2.5 2.5 2.5	2.0 2.0 2.0 2.0	Pwr. Amplifier Triode Triode— Class B Triode— Class B	250 250 300 400	250 Tie Gs to P Tie Gs to G and Su to P	18.0 28.0 0 0	35.0 26.0 10.0‡ 13.0‡	9.0	6,000 5,000 4,600♦ 6,000♦	2,500 2,600	3,000 1,250 15,000 (2 tubes) 20,000 (2 tubes)	
64, 64A	Tetrode	. .	5E	Cath.	6.3	0.40	Amplifier	180	90	3.0	3.1	1.5	500,000	1,050		36
65, 65A	Tetrode		5E	Cath.	6.3	0.40	Amplifier	180	90	3.0	4.5	1.3	750,000	1,000		39 44
67, 67A	Triode	.	5A	Cath.	6.3	0.40	Det. Amplifier	180		13.5	4.3		10 200	9.2		37
68, 68A	Pentode		5E	Cath.	6.3	0.40	Pwr. Amplifier	135	90	13.5	14	3.0	7 500	1,400	650	38
70A7GT	Diode Beam Amplifier	T-9	8AB	Cath.	70.0	0.15	H.W. Rectifier Pwr. Amplifier	125 V. RMS Plate, 60 Ma. Output 110	110	7.5	40	3.0	2,500	5,800	1,500	70L7GT
70L7GT	Diode Beam Pentode	GT	8AA	Cath.	70.0	0.15	H.W. Rectifier Amplifier	117 A C Volts RMS, 70 Ma. Output Current. Capacitor Input to Filter 110	110	7.5	40	3.0	15,000	7,500	1,800	
71	Triode	ST-14	4D	Fil.	5.0	0.50	Pwr. Amplifier	180		40.5	20	.	4,800	3	790	71A
71A	Triode	ST-14	4D	Fil.	5.0 5.0 5.0	0.25 0.25 0.25	Pwr. Amplifier	90 135 180	. . . .	16.5 27.0 40.5	10.0 17.3 20.0	. . . .	3,000 3,000 4,800	3 3 3	125 400 790	
71B	Triode	ST-14	4D	Cath.	5.0	0.125	Pwr. Amplifier	180		40.5	20	.	4,800	3	790	71A
75, 75S	Duodi Triode	ST-12	6G	Cath.	6.3	0.30	Det. Amplifier	250		2.0	0.9		91,000	100	.	
76	Triode	ST-12	5A	Cath.	6.3 6.3 6.3	0.30 0.30 0.30	Amplifier Detector	100 250 250	. . . . . .	5.0 13.5 20.0♦	2.5 5.0 Adjust Bias for 0.2 Ma. Plate Current Without Signal	.	12,000 9,500	13.8 13.8	. . . .	
77	Pentode	ST-12	6F	Cath.	6.3 6.3	0.30 0.30	Amplifier	100 250	60 100	1.5 3.0	1.7 2.3	0.4 0.5	600,000♦ >1.0 Meg.	1,100 1,250	. . . .	
78	Pentode	ST-12	6F	Cath.	6.3 6.3 6.3 6.3	0.30 0.30 0.30 0.30	Amplifier	90 180 250 250	90 75 100 125	3.0 3.0 3.0 3.0	5.4 4.0 7.0 10.5	1.3 1.0 1.7 2.6	300,000 1 Meg. 800,000 600,000	1,275 1,100 1,450 1,650	. . . .	
79	Duo Triode	ST-12	6H	Cath.	6.3	0.60	Pwr. Amplifier	250	Class B	0	21.0	Both Triodes	14,000♦		8,000	6N7

TYPE	CLASS	CONSTRUCTION STYLE	CONSTRUCTION BASE DIAG	EMITTER TYPE	EMITTER VOLTS	EMITTER AMP	USE	PLATE VOLTS	SCREEN VOLTS	NEG GRID VOLTS	PLATE CURRENT MA	SCREEN CURRENT MA.	PLATE ① RESISTANCE OHMS	AMP ② FACTOR OR Gm μMHOS	POWER OUTPUT MW	SUGGESTED REPLACEMENT TYPE
80M	Duo Di M V		4C	Fil	5 0	2 00	F W Rectifier	450 V RMS Per Plate 125 Ma. D C Output								80
81 81M	Diode	ST-16	4B	Fil	7 5	1 25	H W Rectifier	700 A C Volts Per Plate RMS 85 Ma Output Current Condenser Input to Filter								
82	Mercury Vapor Duo Diode	ST 14	4C	Fil	2 5	3 0	F W Rectifier	550 A C Volts Per Plate RMS 115 Ma. Output Current Choke Input—6 Henrys Min 450 A C Volts Per Plate RMS 115 Ma Output Current Capacitor Input to Filter								
82V																82
83	Mercury Vapor Duo Diode	ST-16	4C	Fil	5 0	3 00	F W Rectifier	550 A C Volts Per Plate RMS 225 Ma. Output Current, Choke Input—3 Henrys Min 450 A C Volts Per Plate RMS 225 Ma. Output Current Capacitor Input to Filter								
83V	Duo Diode	ST-14	4AD	Cath	5 0	2 00	F W Rectifier	500 A C Volts Per Plate RMS 175 Ma. Output Current Choke Input—4 Henrys Min 375 A C Volts Per Plate RMS 175 Ma. Output Current Capacitor Input to Filter								5V4G
84/6Z4	Duo Diode	ST 12	5D	Cath	6 3 6 3	0 50 0.50	F W Rectifier	325 A C Volts Per Plate RMS 60 Ma Output Current Condenser Input to Filter 450 A C Volts Per Plate RMS 60 Ma. Output Current 10h Choke Input to Filter								
85	Duodi Triode	ST 12	6G	Cath	6 3	0 30	Det Amplifier	Characteristics Same as Type 6V7G								6V7G
85AS	Duodi Triode	ST-12	6G	Cath	6 3	0 30	Det Amplifier	250		9 0	4 5		16 000	20		85
88	Duo Diode		4C	Fil	5 0	2.00	F W Rectifier	450 V RMS Per Plate 125 Ma D C Output								83V
89	Pentode	ST 12	6F	Cath	6.3 6 3 6 3	0 40 0 40 0 40	Pwr Amplifier Triode Triode Class B	180 160 180	180 Gs+Su to P Tie Su to P	18 0 20 0 0	20 0 17 0 3 0	3 0	8 000 7 000 9 400♦	1 550 4 7 Tie Gs to G	1 500 300 3 500 (2 tubes)	
89Y								Same as Type 89 Has low-loss base								
95	Pentode		6B	Cath	2 5	1 75	Pwr Amplifier	315	315	22 0	42	8 0	7 000	2,300	5 000	2A5
96	Diode		4G	Cath	10 0	0 50	H W Rectifier	350 V RMS Plate 100 Ma D C Output								1V
98																84
X99	Triode	T-9	4D	Fil	3.3	063	Det Amplifier	Same as V99								
117L7GT	Beam Power Diode	T-9	8AO	Cath Cath	117	090	Amplifier H W Rect	105 117 V RMS Plate 75 Ma D C Output Cond Input	105	5 2	43	4 0	4 000	5 300	850	
117L7/M7GT	Diode Beam Amplifier	GT	8AO	Cath	117	0 09	H W Rectifier Pwr Amplifier	117 A C Volts RMS 75 Ma Output Current Capacitor Input to Filter 105	105	5 2	43	4 0	17 000♦	5 300	850	
117N7GT	Beam Power Diode	T-9	8AV	Cath Cath	117	090	Amplifier Rectifier	100 117 V RMS Plate 75 Ma D C Output Cond Input	100	6 0	51	5 0	3 000	7 000	1 200	
117P7GT	Diode Beam Amplifier	GT	8AV	Cath	117 0	0 09	H W Rectifier Pwr Amplifier	117 V RMS Plate 75 Ma D C Output 105	105	5 2	43	4 0	4 000	5 300	850	
117Z4GT	Diode	GT	5AA	Cath	117	0 04	H W Rectifier	117 V RMS Plate 90 Ma D C Output								
182B/482B	Triode	ST-14	4D	Fil	5 0	1 25	Pwr Amplifier	250		35 0	20		4 500	5 0	1 350	71A or 45
183/483	Triode	ST-14	4D	Fil	5 0	1 25	Pwr Amplifier	250		65 0	20		4 500	3 0	1 800	71A or 45
210T	Triode	ST-16	4D	Fil	7 5	1 25	Pwr Amplifier	Standard Type 10 with Ceramic Base See Type 10 Characteristics								
401	Triode		4D	Cath	3 0	1.35	Det Amplifier	90		3 0	5 0		9 500	9 5		27
484	Triode		5A	Cath	2 8	1 60	Det Amplifier	180		9 0	6 0		9 300	12 5		485
950	Pentode		5K	Fil	2 0	0 125	Pwr Amplifier	135	135	16 5	5 5	2 0	13 500	950	575	33
951	Tetrode		4K	Fil	2 0	0 60	Amplifier	180	67 5	3 0	1 7	0 4	1 2 Meg	650		1B4P
9001	Pentode	T-5½	7PM	Cath	6 3	0 15	Det Amplifier	90 250	90 100	3 3	1 2 2 0	0 5 0 7	1 000 000 1 Meg Min	1 400		
9002	Triode	Min	7BS	Cath	6.3	0 15	Amplifier	250		7 0	6 3		11 400	25		
9003	Pentode	Min	7BD	Cath	6 3	0 15	R F Amplifier	250	100	3 0	6 7	2 7	700 000	1 800		

9006	U H F Diode	T-5½	6BH	Cath.	6.3	0.15	Rectifier	270 V. RMS Plate, 5 Ma. D C Output								
XXB	Duo Triode	Lock-In	7BW	Fil.	1.4	0.10	Amplifier	90	. . .	0	4.5	.	11,200	14.5	.....	
XXD	Duo Triode	Lock-In	8AC	Cath.	12.6	0.15	Amplifier	See Type 14AF7/XXD								
XXFM	Duodi Triode	Lock-In	8BZ	Cath.	6.3	0.30	Det. Amplifier	See Type 7X7.								
XXL	Triode	Lock-In	5AC	Cath.	6.3	0.30	Amplifier	100 250	....	0 8.0	10.0 8.0		7,000 8,700	25 20	....	7A4

BASE DIAGRAMS FOR CONDENSED DATA CHART

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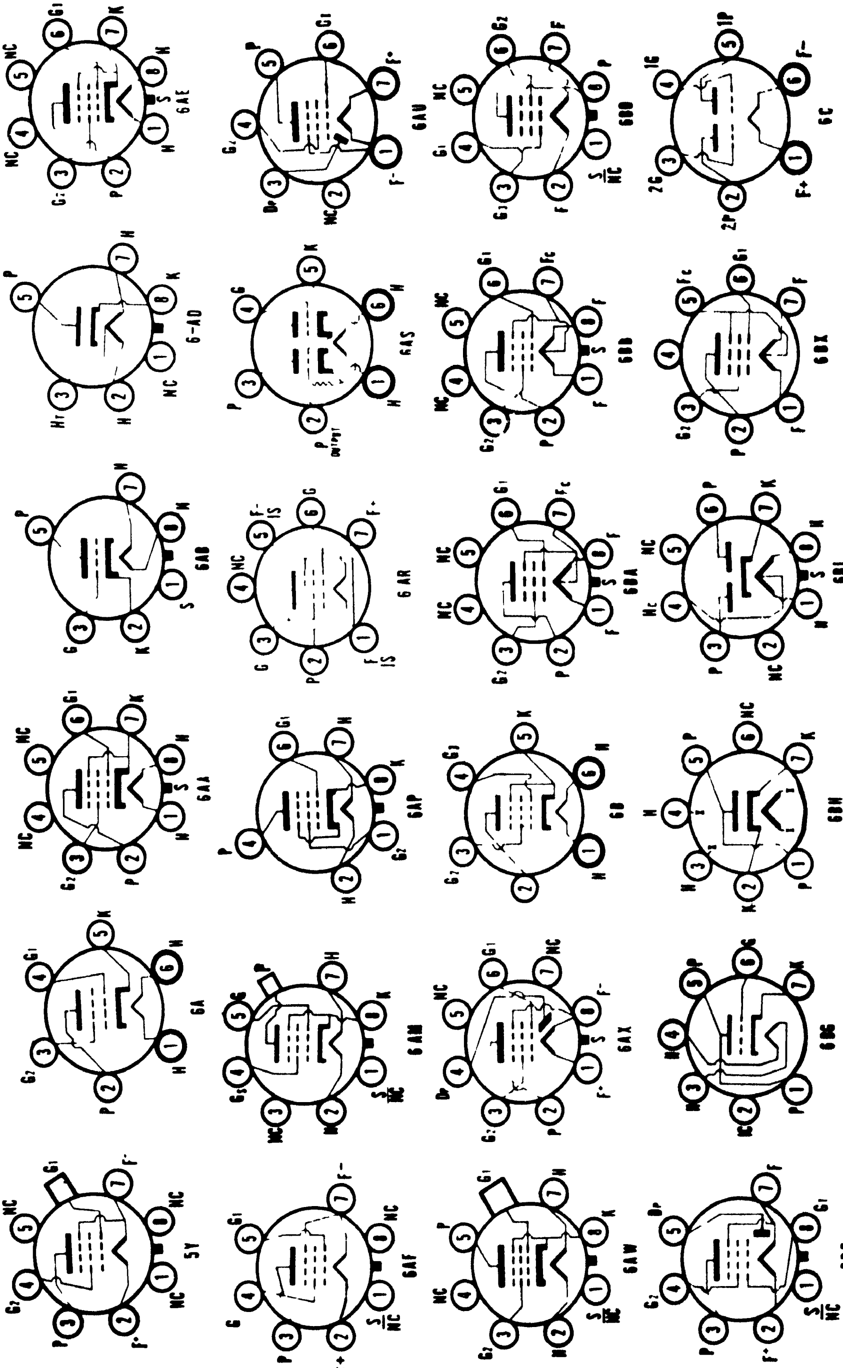

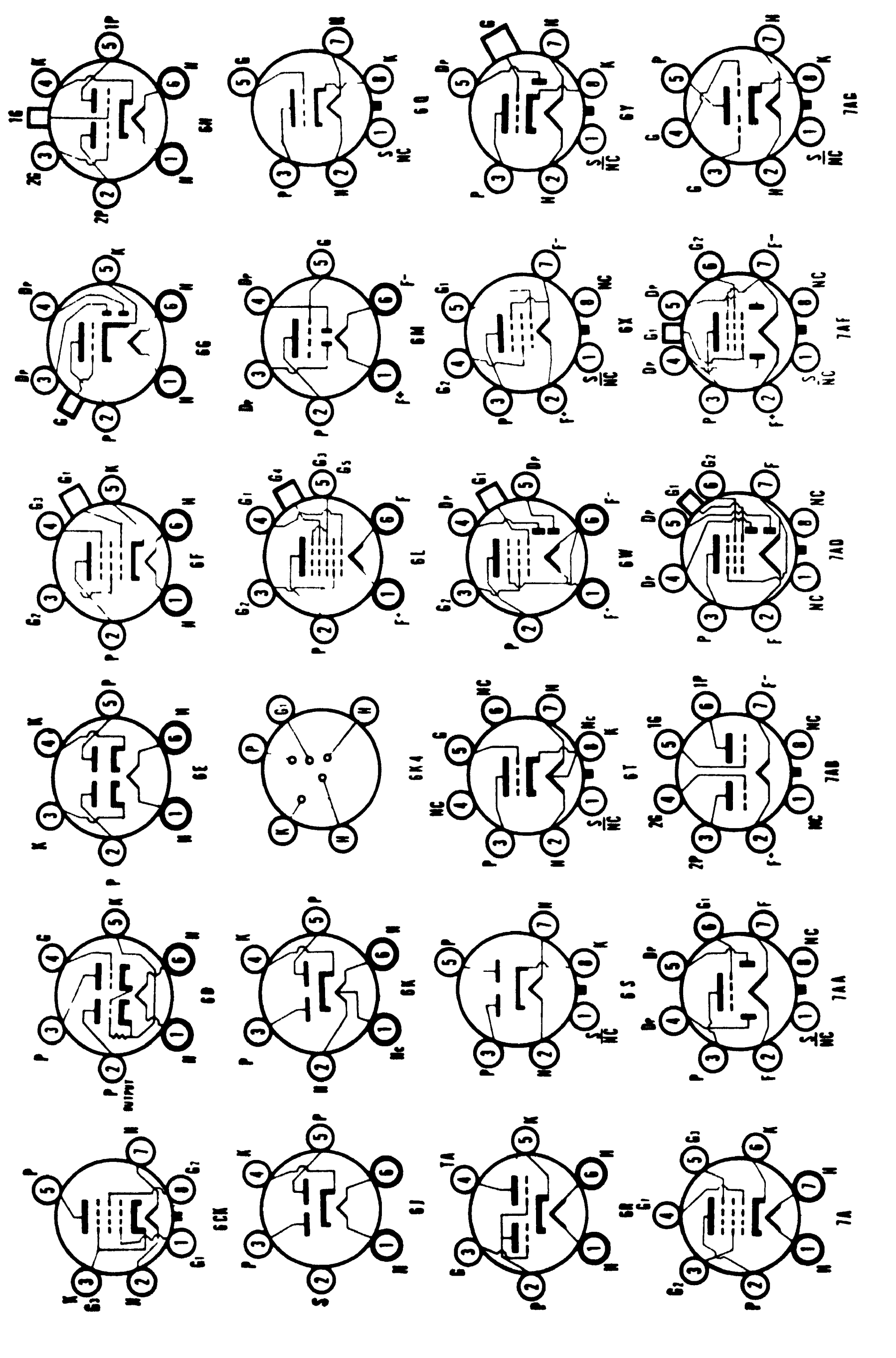

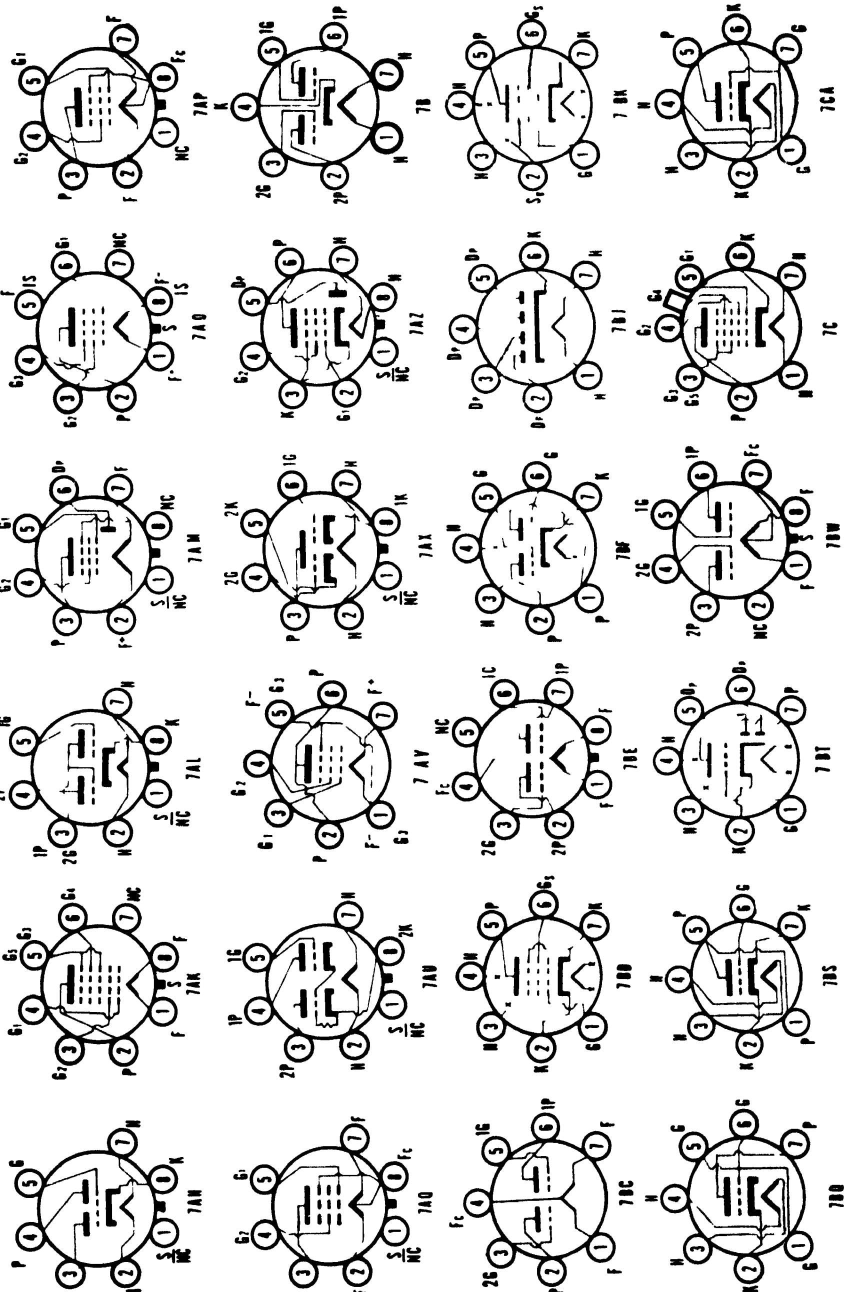
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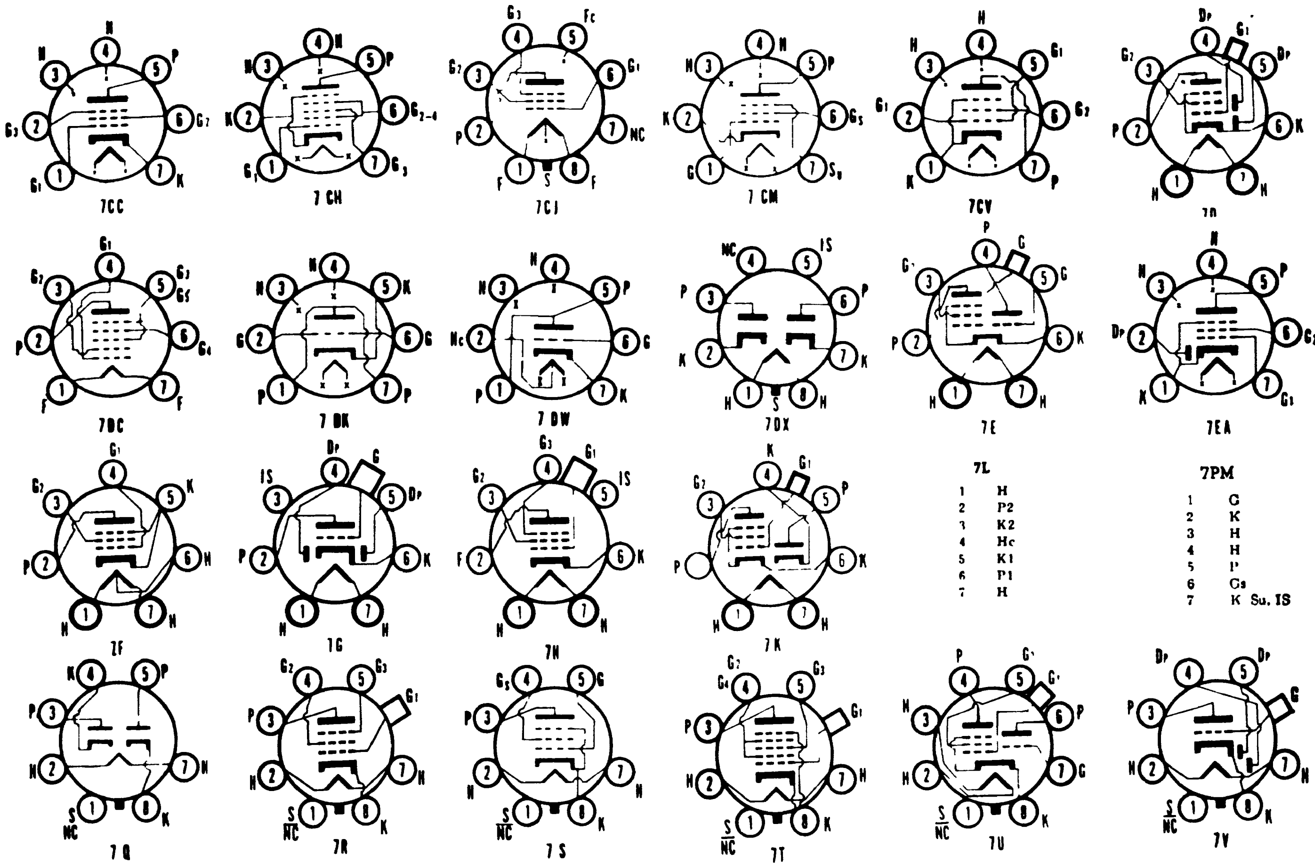
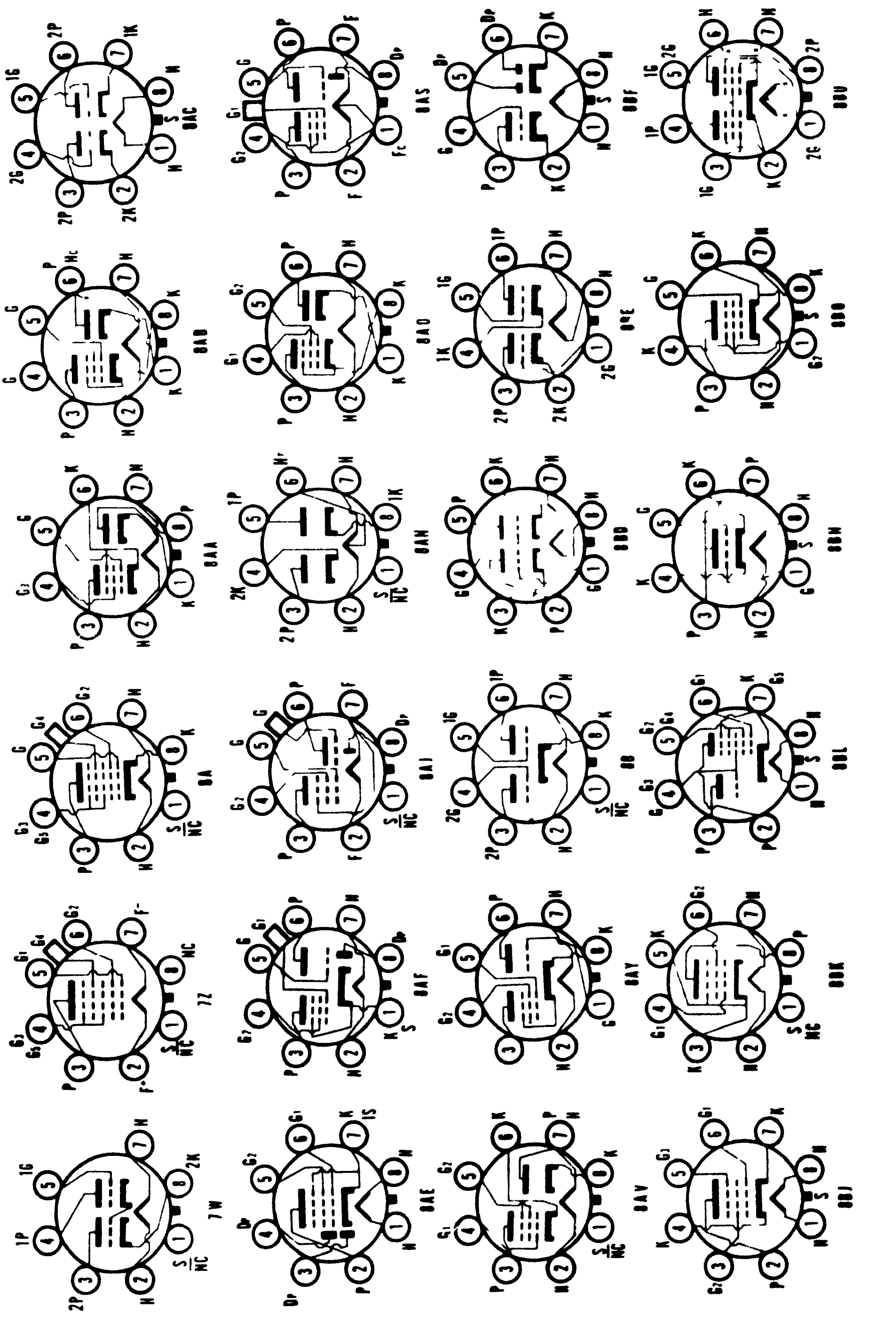


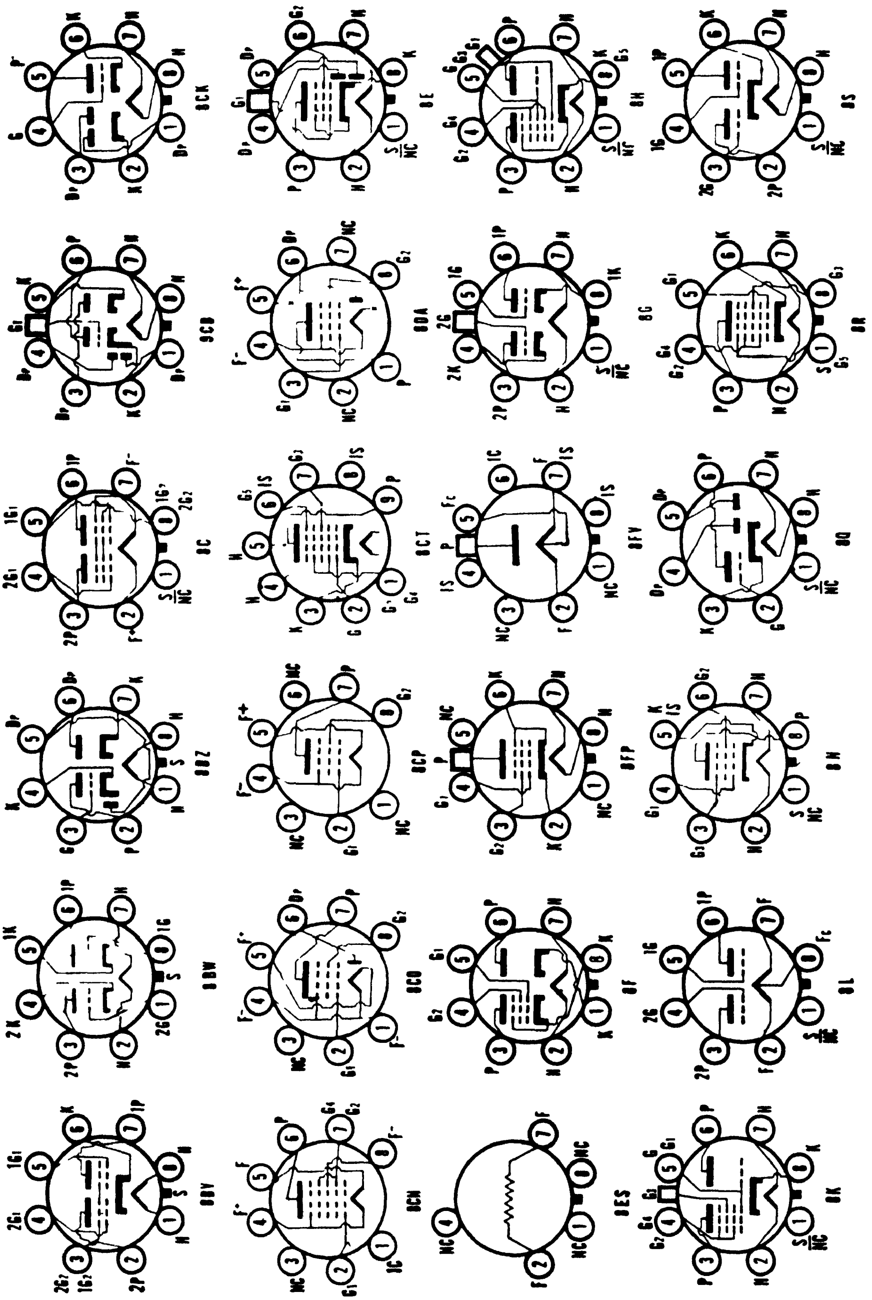
7L

1	H
2	P2
3	K2
4	Hc
5	K1
6	P1
7	H

7PM

1	G
2	K
3	H
4	H
5	P
6	G3
7	K Su. IS

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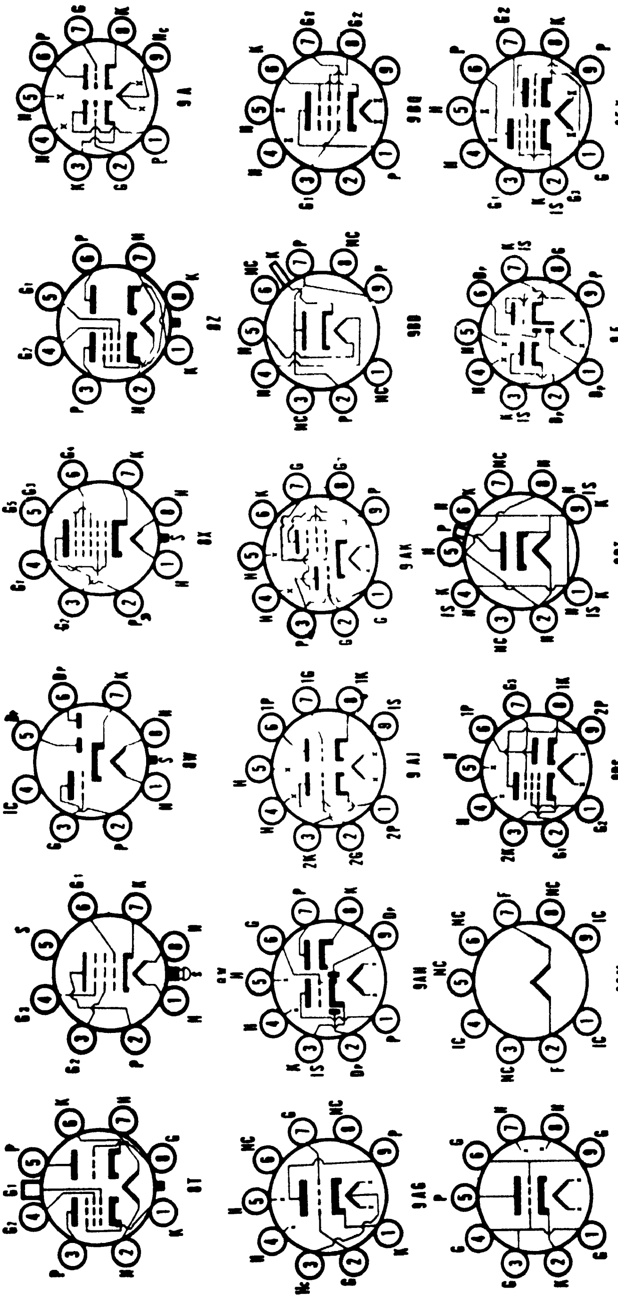
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9AG
9BX

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